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Abstract

This deliverable is intended to provide an initial report on 5G scenarios, use cases and the associated high level requirements. These scenarios and use cases are based on the existing scientific publications in the area, but are specifically redefined in the context of testing both applications and devices. Moreover, we identify the potential metrics and key performance indicators necessary to define the TRIANGLE mark.

Keywords

5G, KPI, Metric, Measurement, Mark, ITU-R, 3GPP, ETSI, LTE, LTE-A, Wi-Fi, Automotive, Internet of Things



Executive summary

This deliverable entitled “Initial report on the testing scenarios, requirements and use cases” reports the work performed by the consortium around several definitions needed to create the first release of the Triangle Testing Framework. This document is the first deliverable of WP2. WP2 focuses on the “Requirements analysis for benchmarking of wireless applications and devices”.

The document is a central piece in the overall definition of the way an app, or device or service will be tested, against which scenarios, criteria and how we come to an answer related to the Triangle mark. The document is not the final version that reflects the overall process, but is already detailed enough to ensure all the elements developed in the test bed will be aligned towards the same objective and metrics.

The focus of the document is on the definition of the 5G expected type of services and under which physical conditions the use will be happening. This leads to the understanding of the high level scenario in which devices and Apps will be exposed or used. When this high level understanding was completed, work was performed to agree on how the Triangle mark would look like, and what component will be taken into account to compose it. At this stage, given the expected evolution of 5G, we cannot claim the mark is yet mature. We anticipate regular critical review and improvements over the rest of the project duration. Finally, the perspective of the testbed user is taken to reflect on the interface they will be exposed too as well as the type of detailed measurements needed.

We expect, with the realisation of the first trials in 2017, that several points will be learned and used to improve the preciseness of the steps described in this document. A second, and more extended version of this document will be published by the summer 2017 under D2.2.

The appendixes to the document go further into detail on the test cases (including all pre conditions), provide an overview of the IoT OS (a highly dynamic field), and more details on the available parameters of some of the core components of the test bed.

The guidelines on how experiments will take place on the Triangle Testing Framework has been described in D5.1.



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List of Abbreviations

| | |
|----------------|--|
| 2G | Second generation wireless technology |
| 3G | Third generation wireless technology |
| 3GPP | 3rd Generation Partnership Project |
| 4G | Forth generation wireless technology |
| 5G | Fifth generation wireless technology |
| 6LoWPAN | IPv6 over Low power Wireless Personal Area Networks |
| ABS | Almost Blank Sub frames |
| AMF | Authentication Management Field |
| AP | Access Point |
| APN | Access Point Name |
| BLE | Bluetooth Low Energy |
| BS | Base Station |
| BSSID | Basic Service Set Identifier |
| C-RNTI | Cell Radio Network Temporary Identifier |
| CBOR | Concise Binary Object Representation Implementations |
| CDMA | Code Division Multiple Access |
| CFI | Control Format Indicator |
| CO | Confidential |
| CoAP | Constrained Application Protocol |
| CQI | Channel Quality Indicators |
| CSI-RS | Channel State Information Reference Signal |
| D | Deliverables |
| DC | Dual Connectivity |
| DCI | Downlink Control Indicator |
| DL | Downlink |
| DNS | Domain Name System |
| DRB | Data Radio Bearer |
| DRX | Discontinuous Reception |
| DTLS | Datagram Transport Layer Security |

| | |
|----------------|---|
| DTX | Discontinuous Transmission |
| EC-GSM | Extended Coverage GSM |
| eICIC | enhanced Inter-Cell Interference Coordination |
| eNB | Evolved Node B |
| EPC | Evolved Packet Core |
| ESSID | Extended Service Set Identifier |
| ETSI | European Telecommunications Standards Institute |
| E-UTRAN | Evolved UTRAN |
| FDD | Frequency Division Duplex |
| GPRS | General Packet Radio Service |
| GSM | Global System for Mobile communications |
| HARQ | Hybrid automatic repeat request |
| IEEE | Institute of Electrical and Electronics Engineers |
| IMSI | International Mobile Subscriber Identity |
| IoT | Internet of Things |
| IR | Internal report |
| JTAG | Joint Test Action Group |
| KPI | Key Performance Indicator |
| LAC | Location Area Code |
| LAN | Local Area Network |
| LTE | Long Term Evolution |
| LTE-A | Long Term Evolution-Advanced |
| LTE-M | Long Term Evolution For Internet of Things |
| M | Milestones |
| Mbit/s | megabits per second |
| Mo | Month |
| MAC | Media Access Control |
| MCS | Modulation Coding Scheme |
| MIMO | Multiple-Input Multiple-Output |
| MMC | Massive Machine Communication |
| M2M | Machine to Machine |
| MTC | Machine Type Communications |



| | |
|----------------|--|
| NAS | Network Access Stratum |
| P-CSCF | Proxy Call Session Control Function |
| PBCH | Physical Broadcast Channel |
| PC | Project Coordinator |
| PCFICH | Physical Control Format Indicator Channel |
| PDCCH | Physical Downlink Control Channel |
| PDCP | Packet Data Convergence Protocol |
| PDSCH | Physical Downlink Shared Channel |
| PDU | Packet Data Unit |
| PHICH | Physical Hybrid-ARQ Indicator Channel |
| PM | Pre-coding Matrix |
| PRACH | Physical Random Access Channel |
| PSM | Power Save Mode |
| PSS | Primary Synchronization Signal |
| PU | Public |
| PUCCH | Physical Uplink Control Channel |
| PUSCH | Physical Uplink Shared Channel |
| QAM | Quadrature Amplitude Modulation |
| QoE | Quality of experience |
| QoS | Quality of Service |
| RAN | Radio Access Network |
| RAT | Radio Access Technology |
| REC | 'Radio Equipment Controllers' |
| RF | Radio Frequency |
| RI | Rank Indicator |
| R&D | Research and Development |
| RLC | Radio Link Control |
| RLM | Radio Link Monitoring |
| RPL | IPv6 Routing Protocol for Low-power and Lossy Networks |
| RRH | Remote Radio Heads |

| | |
|-----------------|---|
| RRM | Radio Resource Management |
| RSCP | Reference Signal Code Power |
| RSRP | Reference Signal Received Power |
| RSRQ | Reference Signal Received Quality |
| SCC | Secondary Cells Carriers |
| SCPI | Standard Commands for Programmable Instruments |
| SISO | Single Input Single Output |
| SL | Side Link |
| SRS | Sounding Reference Signal |
| SSS | Secondary Synchronization Signal |
| T | Task |
| TAC | Tracking Area Code |
| TCP | Transport Control Protocol |
| TD-SCDMA | Time Division Synchronous Code Division Multiple Access |
| TDD | Time Division Duplex |
| TLS | Transport Layer Security |
| TPC | Transmit Power Control |
| TS | Technical Specification |
| UBJSON | Universal Binary JSON |
| UDP | User Datagram Protocol |
| UE | User Equipment |
| UL | Uplink |
| UMTS | Universal Mobile Telecommunications System |
| UTRAN | UMTS Terrestrial Radio Access Network |
| WAN | Wide Area Network |
| WG | Working Group |
| WFA | Wi-Fi Alliance |
| WLAN | Wireless Local Area Network |
| WP | Work Package |



1 Introduction

This deliverable starts, in Section 2, with the preliminary set of 5G use cases which initially have been identified to fall within the scope of TRIANGLE project. They have been classified into three main categories: extreme mobile broadband (xMBB), massive Machine-Type-Communications (mMTC), and ultra-reliable MTC (uMTC).

Some of the widely discussed testing scenarios for 5G are presented in Section 3, from the perspective of the end user, rather than an aggregated network-wise vision. Section 4 describes what 5G networks are expected to offer in those testing scenarios for devices and applications.

Section 5 introduces key concepts in TRIANGLE project such metric, measurement, and KPI which paves the way to the definition of the Triangle Mark. This section also presents a preliminary identification of metrics and KPIs of interest for applications and devices in the context of 5G.

The focus of TRIANGLE Project is the development of a testing framework. The implementation is mainly targeted in WP3 and WP4. From a system engineering perspective, this deliverable covers the first three phases of the development process:

- Identification of the users of the system (Section 6): App developers, device makers, researcher and mobile network operator.
- Identification of the potential interactions between the users and the Testing Framework (Section 7).
- Identification of measurement capabilities (Section 8) and requirements (Section 9) of the Testing Framework.

This deliverable sets the grounds for the formalization of the test cases and certification process for testing 5G devices and application, which will be covered in the deliverable D2.2.



2 5G Use Cases in the Context of Testing

5G core services can be classified into three main categories.

The first category, denoted as extreme mobile broadband (xMBB), is characterized by extremely high data rates and low-latency communications with very high coverage levels.

The second category, denoted as massive Machine-Type-Communications (mMTC), encompasses the massive number of foreseen devices that will be connected to the network.

The third and last categories, denoted as ultra-reliable MTC (uMTC), refers to ultra-reliable and ultra-low latency communication services.

This categorization of the core services allows us to identify the main aspects for testing. Generally speaking, xMBB and uMTC main concerns are latency, throughput, availability and how the application copes with variations of those in different scenarios. Similarly, mMTC testing is mainly concerned with overload aspects due to the massive number of devices in the system, delivering the reports to the server before a given deadline (i.e., reliability) and battery consumption as these devices are typically expected to last for a minimum of ten years.

In the following sections we describe showcase applications in the context of 5G services. These applications could potentially belong to one or multiple of the categories depending on the characteristics of such application.

2.1 Virtual Reality (VR)

Virtual reality (VR) is the term used to describe a three-dimensional, computer generated environment which can be explored and interacted with by a user. That user becomes part of this virtual world or is immersed within this environment and whilst there, is able to manipulate objects or perform a series of actions.

Multiple sub-systems in the device are involved such as the GPS, the camera, the accelerometers, the speakers, and the microphone. It is roughly estimated that humans can process 5.2 Gbit/s of sound and light. This value serves as rough estimate for the maximum required data rate. A more conservative value is 300 Mbit/s, which is slightly above a 4K movie experience [1]. Latency is also a considerable factor for the VR experience. Ideally, the latency should be below 15 ms, but today's devices such as the Oculus Rift can achieve latency of about 30-40 ms [2].

VR is an emergent technology which presents considerable challenges for testing due to the large number of aspects to take into account. Appendix 4 summarizes the result of research on testing Android based VR apps.

Categorie(s): xMBB.

2.2 Gaming

The mobile game revenue is expected to exceed the console and PC games in 2016 for the first time [3].

Gaming is a particularly challenging case where each game presents its own requirements. Moreover, games do not longer purely rely on user-screen interaction, but encompasses multiple components such as GPS, camera, accelerometers, etc. The network demand is also



quite different from one game to another. However, two main aspects are to be highlighted: latency and throughput. Latency in gaming is a key aspect, it is typically assumed that for non-VR games a delay of about 50 ms is tolerable [2]. An upper limit in terms of throughput is 4K resolution, which means an average of 50 Mbit/s.

Categorie(s): xMBB.

2.3 Content Distribution Streaming Services

With the ever increase of services like Netflix or Amazon Prime, streaming services are a key application to consider in the context of the 5G services.

Customers make use of such services everywhere: home, public transportation, cars, trains, etc. These services are downlink centric with extremely high data throughput requirements in the downlink; while the uplink is only used for controlling the stream.

Nowadays streaming services such as Netflix requires 5 Mbit/s for HD video and 25 Mbit/s for ultra-HD. The quality of the video can be downgraded if the user network is not good enough; being 0.5 Mbit/s the absolute minimum that the service requires for minimal operation [4].

Categorie(s): xMBB.

2.4 Live Streaming Services

5G users will increasingly demand broadcasting and sharing their experiences through live video. Live streaming services demand both downlink and uplink bandwidth which is a key difference from content distribution services where only downlink resources are required.

Nowadays, the offered resolution through these applications is limited to Standard Definition range thus leaving room for better quality resolution in the context of 5G services.

Categorie(s): xMBB.

2.5 High Speed Internet

One of the most common applications for 5G will still be internet broadband access. While current internet speeds are somehow acceptable for existing services and websites, there is a continuous trend in making websites heavier and fancier.

In order to maintain a good quality of experience for the users and a low loading time it is required that internet access speed increases accordingly. The availability of the service with such speeds can be quite challenging in certain scenarios

The number of applications and services that make use of high speed internet is very extensive. However, it is commonly assumed that the "*broadband everywhere*" will provide a minimum of 20 Mbit/s "everywhere". Thus, this is the minimum throughput that services in this category are expected to cope with.

Categorie(s): xMBB.



2.6 Smart Metering (SM)

Smart metering is a showcase of the Internet of Things (IoT), where thousands of meters are placed in homes reporting the energy consumption without human interaction.

Each household is expected to have two to three smart meters: electricity, water/heating and gas. The amount of information to be sent to the remote server is in the order of bytes and in most cases the report is delay tolerant [5].

Smart metering is driven by reliability rather than throughput, where it is of essence that a generated report arrives to the remote server before a certain deadline, which could span from minutes to hours depending of the utility company requirements. These devices are also expected to last for considerable amount of time, typically 10 years. Thus, battery consumption is also an important aspect to test.

Categorie(s): mMTC.

2.7 Smart Grids (SGs)

Smart Grid (SG) is the evolution of the traditional power grid with the primary goal of delivering reliable and secure electricity supplies.

With the increase of renewable energies, such as wind power or solar power, communications become more important to balance and protect the grid from sudden increases/decreases of energy production by the renewable sources. Moreover, due to such fluctuations the need to monitor the power grid is becoming more and more important.

In terms of requirements SGs require closer inspection of the grid, which in turn require more reports per minute. An upper limit on these requirements is one report every 1/50 seconds (20 ms); corresponding to the fastest the grid can change (50Hz). However, a more conservative value is reporting the grid every second [5].

Categorie(s): mMTC, uMTC.

2.8 Connected Vehicles

Self-driving cars is a popular topic nowadays, where ultra-reliable and ultra-low latency communications play a fundamental role. The cars need to communicate with traffic lights/signs and with other cars in the vicinity for safety reasons.

Categorie(s): uMTC.

2.9 Patient Monitoring

Patient Monitoring is a highly investigated use case since it could allow to quickly release the patient to his or her home, fastening the healing process while cutting the hospitalization expenses at the same time.

The typical scenario is then an urban indoor, private space (patient home). It is expected that the traffic generated by sensors runs through a monitoring hub, that relays it to the access network.

The type of traffic expected is mostly small and infrequent packets, similarly to the IoT type. Few longer streaming sessions (e.g., video conferencing of vitals streaming) are also expected together with some data dump (uploading sessions).



Categorie(s): xMBB, uMTC.

2.10 Emergency Services

It is expected that the systems in the ambulance could generate a massive live stream of data, combining voice, video, and patient vitals. This type of traffic should be considered as higher priority traffic in the network, compared to the commercial one.

There is already a commercial product available to undergo testing and certification on the Triangle Testing Framework, by RedZinc. This product is called BlueEye and is a new wearable video technology which combines with a software defined 5G network slicing solution. This solution provides unprecedented support to emergency service first responders using live interactive and wearable point-of-view video from the first responder back to the hospital or command center.

Categorie(s): xMBB, uMTC.



3 5G Testing Scenarios

In this section some of the widely discussed scenarios for 5G are presented. In contrast to what is available in the literature (see [6] and references within), the TRIANGLE project aims at the perspective of the end user, rather than an aggregated network-wise vision. Additional specific use cases of interest for App developers and IoT device manufacturers have been then derived.

The 5G usage scenarios have been divided into macro categories according to their commonalities in the network deployment and channel conditions. Each usage scenario is then sub-divided into user and traffic present in the surroundings.

3.1 Urban

The urban scenarios are generally characterized by dense urban network deployments. One can think about locations like the London City center, or Manhattan, or Tokyo. Network deployments in urban scenarios are usually characterized by the presence of Macro sites with a reduced or highly reduced inter-site distance, together with the presence of Small Cells as well. Given the need of carrying high amount of traffic, a dense HetNet is required, giving the possibility to the terminal to be connected to Small Cells as Primary Cell as well.

Under this umbrella several 5G usage scenarios characterized by the location and mobility of the users have been identified.

3.1.1 Office

This is the typical indoor office environment where users are static. It is characterized by the presence of indoor wireless network access points (both Wi-Fi and Small Cells). The channel and interference conditions are also dictated by the penetration of signals coming from the outdoor cells, mostly macro sites. The expected traffic scenario is related to typical broadband access with a mixture of applications.

3.1.2 Pedestrian

This is the usual scenario of a user walking down an urban street at 1 to 3 km/h. It is expected that the channel conditions can change due to the presence of moving obstacles e.g. trucks and buses. Even in this case a typical broadband access is the baseline for the traffic-generating applications.

3.1.3 Driving

It is becoming more and more common to have wireless modems inside the car that allow direct connectivity to the onboard computer and entertainment system. Given the urban environment, the expected speed of the vehicle is up to 60 km/h. The traffic conditions are here very dependent on the application, since V2I traffic for vehicular control could also be foreseen.

3.1.3.1 Normal

In normal vehicular traffic conditions, the speed is expected to be on the high end of the urban limits, possibly 40 to 60 km/h. The density of the users on the road is here reasonably low, given the regulatory distance between vehicles.



3.1.3.2 Traffic jam

In a traffic jam it is expected that the vehicles will be more packed, resulting in a higher density, while the speed tends to be from very low to almost static. The users are then expected to do a heavier use of, for example, their own entertainment system creating a heavier load on the network.

3.1.3.3 Emergency Driving

An interesting case for e-health is the path that an ambulance is following when called for an emergency. Despite of the urban settings, the ambulance is allowed to drive faster than the limits (60 to 120 km/h). While the ambulance is the most important civilian case, the same type of scenario could be applied to public forces acting on emergency calls for safety and security, from fire fighters to police.

3.1.4 Internet Cafè

While this scenario can be substantially derived from both the office and pedestrian one, we believe it has a value for the App developers, and it is fairly easy to understand for non-experts. The scenario is a typical multi-RAT scenario with users mostly static, with some channel variations due to the street-level nature of the location (moving objects on the street, some indoor penetration).

3.1.4.1 Busy Hours

During for example lunch hours on a weekday the cafè is expected to be full of customer who are trying to access the network for consuming services. This affects the network load and the amount of resources that each customer can get from the network.

3.1.4.2 Off-Peak

During for example a mid-afternoon the amount of customers in the cafè decreases, creating easier conditions for network access. At the same time the type of imperfections that affect the channel (interference from other customers, amount of moving shielding objects) is also reduced.

3.2 Sub-Urban

The sub-urban umbrella contains all those scenarios which are generally located outside the city centre, in less densely populated areas. For this reason, most of the access site to the network is macro only, mounted on higher rise towers for coverage, with a larger inter-site distance.

Few sporadic Small Cell hotspots are eventually encountered within the coverage area of the macros, either for localized capacity boosting or for reinforcing the coverage. All the sub-cases of interest in these network and propagation conditions are related to the concentrated and massive presence of users.

3.2.1 Festival

This usage scenario is typically outdoor, with additions of few localized macro sites and Small Cells for increased capacity. The type of expected traffic is mostly consistent with a very dense broadband access, with eventual broadcasting of the concerts in the area of the festival.



3.2.2 Stadium

This is the scenario with the highest density of users. Hotspots cover the stadium area, but its main characteristic is the balancing between the amount of access points and the interference generated.

3.2.3 Shopping Mall

The physical environment is characterized by indoor large spaces, with a certain amount of electromagnetic reflecting materials. Mixed applications are expected to run in the network, for both business internal and external customers' purposes.

3.2.3.1 Busy hours

Considering e.g. a Saturday noon, the Shopping Mall is expected to be flooded with customers, and both the business internal and customers' traffic is expected to overload the network.

3.2.3.2 Off-Peak

Fewer customers present in the premises, partly changing not only the traffic but also the propagation conditions as well.

3.3 High speed train

High speed collective transport, similarly to current scenarios present in Japan, is considered a valuable scenario for 5G where both commercial traffic and critical vehicular control should coexist in the same radio access. The propagation condition is a rural one, with relatively sparse macro sites densified for the railroad coverage purpose. The speed of the train is very high, up to 350 km/h. Two different ways of dealing with the users' affiliation represent the main technical challenges for 5G and how the system should behave.

3.3.1 Relay

One way of dealing with the users' affiliation to the network is by installing a relay (or self-backhauled as sometimes referred to in 5G literature) or an access gateway for Wi-Fi on the train. Since there is only one device affiliated to the fixed wireless network, the C-plane is not the bottleneck, but the aggregated traffic of all the users creates a massive "super-user" which requires great amount of the U-plane resources.

3.3.2 Direct passenger connections

In contrast to the previous scenario, each user is dealt individually by the fixed network. While each user has a limited amount of U-plane resources to be scheduled, the C-plane and in particular the so-called "massive handover" can create difficulties to the networks and impairments to the data flow for the users, impacting their QoE.

3.4 Internet of Things

Given the radically different nature of the devices and the traffic, IoT requires a category on its own. The devices are usually low-power, low performance. The traffic is heavily sporadic and consists of very small packets, roughly around 160 bytes.



3.4.1 Warehouse

This scenario represents IoT devices which are located in typical industrial setting, i.e., a warehouse, where multiple metallic structures often block the signal and introduce harsh environment to the RF signal.

3.4.2 Outdoor sensors

This scenario represents the situation where outdoor sensors are massively deployed in an urban setting [7]. The major issue of this scenario is the amount of interference generated by the other devices trying to access the network.

3.4.3 Home sensors (basement)

Another scenario of interest is the deployment of home sensors for, e.g., electricity measurement. While power consumption is not a major issue for such devices since they are connected to the power grid, the coverage conditions can be poor, due to the nature of the installation, possibly in a basement with thick walls, where absorbing and reflecting materials heavily shadow the device.

3.5 Selected Scenarios For Further Description

In this section we describe the most relevant scenarios introduced in Section 3.

The selected scenarios are Urban Pedestrian (see Section 3.1.2) and Home Sensors (see Section 3.4.3). The first scenario has been selected as it presents some interesting challenges for further investigation in TRIANGLE, such as occasional handovers to neighbouring cells or variation in the radio conditions due to the user moving across the cell. The second scenario corresponds to a showcase in IoT, where devices are located in difficult to reach positions with extremely challenging radio conditions (20 dB extra with respect to legacy LTE).

Further identifying the main aspects to consider for end to end testing is the purpose of this deliverable. Therefore, the description of these scenarios is qualitative rather than quantitative. In fact, with the exception of the channel model, the scenarios are considered static.

Once the main aspects have been identified and studied in detail, we proceed with a qualitative description of the scenarios, where the conditions will vary over time.

For example, in a pedestrian scenario new cells will appear forcing the UE to perform handovers. In the home sensors case, the cell could potentially disappear for certain periods of time.

We have identified the following main parameters for the network scenarios:

Table 1 - Main parameters for the network 5G scenarios

| Parameter | Description |
|-----------------------|--|
| <i>Received Power</i> | This parameter fixes the perceived signal power at the device side assuming ideal conditions. High values are used to establish good signal coverage, while low values are necessary to emulate bad signal conditions. For example, extremely low values could be used for the home sensors scenario enabling test under very harsh conditions for the IoT device. |
| <i>Duplex Mode</i> | This parameter determines the mode of operation in LTE cells: FDD or TDD. TDD |



| | |
|-----------------------------------|--|
| | enables dynamic adaptation to the load on the cell; while FDD uplink and downlink resources are symmetric. Slight variations between both modes could be observed depending on the TDD configuration. |
| <i>Transmission Mode</i> | This parameter configures the way the downlink radio channel operates. There are nine different modes, each one has associated a downlink antenna configuration. |
| <i>Downlink/Uplink Bands</i> | These parameters fix the downlink and uplink frequencies. IoT devices are expected to reside in the lower part of the spectrum allocated to mobile operators as the penetration properties are better the lower the frequency is. |
| <i>Downlink/Uplink Bandwidth</i> | These parameters fix the capacity of the system both in downlink and uplink. The maximum system throughput is severely affected by the values chosen. These parameters only apply to LTE. LTE-M and NB-IoT have fixed bandwidth. |
| <i>Cyclic Prefix</i> | Depending on the cyclic prefix the information is more resistant to fading, which ultimately will determine the performance of the system. |
| <i>CFI</i> | The Control Format Indicator (CFI) defines how many OFDM symbols are used for the PDCCHs in a subframe. |
| <i>Specific TDD configuration</i> | This parameter fixes the amount of resources devoted to uplink or downlink. When in use is expected to have significant impact in the difference between downlink and uplink system throughput. |
| <i>NB-IoT Mode</i> | NB-IoT defines three main of operations: in-band, guard-band and standalone. Each operation mode faces different challenges and need to be studied in detail. |
| <i>Number of Tones</i> | NB-IoT maximum throughput will depend on the number of tones supported by the IoT devices. We expect most of the first generation NB-IoT devices to be single tone. |
| <i>Carrier Assignment</i> | These parameters determine the type and number of active cells, i.e., primary cell, secondary cell or NB-IoT cell. |
| <i>Carrier Setup</i> | These parameters determine the type of aggregation type, which will have significant impact on the system throughput. |
| <i>Downlink Scheduling</i> | The following downlink scheduling parameters will have significant impact on the system performance. These are: <ul style="list-style-type: none">• Downlink Antenna Configuration• Resource Allocation• Modulation used• Support for 256-QAM |
| <i>Downlink RB Allocation</i> | This parameter determines the amount of resources, i.e., resource blocks, allocated to the device. Thus, the maximum throughput allocated to the UE. For example, scenarios with high load can be emulated by providing limited resources to the device. |
| <i>Uplink Scheduling</i> | The following unlik scheduling parameters will have significant impact on the system performance. These are: <ul style="list-style-type: none">• Modulation used• Support for 64-QAM |
| <i>Power control</i> | This parameter allows to configure the power level used by the UE for PUSCH and PUCCH channels. |
| <i>HARQ</i> | The number of maximum retransmissions will have a considerable impact on the reliability of the system. If the number is too low, a device experiencing bad radio conditions will be challenged to deliver its data in a reliable manner. On the other |



| | |
|------------------------------|--|
| | hand, if the number is too high the efficiency of the system might be affected. |
| <i>Connected DRX</i> | The DRX-configuration is expected to have significant impact on the device's battery life. |
| <i>Measurement reporting</i> | This parameter includes: <ul style="list-style-type: none">• Periodic CSI (Channel State Information) reporting. When enabled, the UE is configured to periodically transmit CQI/PMI/RI reports. These reports must be activated to support the use of adaptive modulation in the downlink.• Aperiodic CSI report |
| <i>Impairments</i> | The impairments described in Section 13 are expected to have significant impact on the system and device performance. Here we highlight the following: <ul style="list-style-type: none">• Orthogonal Channel Noise Generation, which is used to model virtual devices in the network.• Channel emulator, which is used to determine the channel experienced by the devices, e.g., pedestrian, vehicular, high speed train, etc.• AWGN Noise |

With the exception of channel impairments, the aforementioned main network scenario parameters are static. However, we note that these scenarios will grow in complexity over the duration of the project. This is necessary to achieve our goal of realistic testing scenarios. Some of the dynamic parameters to consider in the short-term are described in Table 2.

Table 2 - Dynamic parameters for the network 5G scenarios

| Parameter | Description |
|---------------------------|--|
| <i>Handovers</i> | We expect to emulate scenarios where it is necessary to perform a handover to a neighbouring cell. Several parameters will impact the time necessary to complete the handover. Therefore, the application and the device itself will need to cope with lack of data plane for a short to large period of time. |
| <i>Dynamic Conditions</i> | Consider for example a showcase in IoT, where a device is located on a wall in a shop. If this wall is located next to a parking spot, the signal strength could significantly change over time. For instance, poor signal could be received if there a large truck park in front during business hours; while very good signal conditions could be experienced during the night if no vehicle is park in front. |

In the following sections we present the aforementioned main network parameters to be applied for the two selected scenarios.

3.5.1 Description of Home Sensors Network Scenario

Table 3 - Home Sensors Network Scenario Parameters

| Parameter | Description |
|----------------------------|---|
| Received Power | -130 dBm to – 131.21 dBm ¹ / 180kHz |
| Duplex Mode | FDD |
| Downlink/Uplink Bands | Band number 8 [8] ² . |
| Downlink/Uplink Bandwidth | 10 MHz. |
| Cyclic Prefix | Normal. |
| Specific TDD configuration | N/A |
| NB-IoT Mode | In-Band. ³ |
| Number of Tones | 1 (Single Tone). |
| Carrier Assignment | 1 Primary Cell (LTE) with 1 in-band NB-IoT cell. |
| Carrier Setup | N/A |
| Downlink Scheduling | <ul style="list-style-type: none">Downlink Antenna Configuration: 1x1Resource Allocation: single tone.Modulation Coding Scheme: 0.⁴DCI Repetition Index: 4 (16 repetitions) |
| Downlink RB Allocation | N/A |
| Uplink Scheduling | <ul style="list-style-type: none">Modulation Coding Scheme Index: 0.UCI Repetition Index: 4 (16 Repetitions) |
| HARQ | N/A |
| Connected DRX | N/A |
| Impairments | <ul style="list-style-type: none">Pedestrian channel with low Doppler.⁵AWGN Noise |

¹ The received power is tailored to the sensitivity of the device. The expected coupling loss is approximately 160 dB, which corresponds to the +20dB extra in NB-IoT with respect to legacy LTE.

² There are 14 bands defined for NB-IoT, which are in the lower range of existing LTE bands.

³ Although NB-IoT has not been commercially deployed at the moment of writing this document, we expect that NB-IoT cells will be deployed in in-band configurations, exploiting the existing infrastructure.

⁴ Corresponding to the most robust modulation coding scheme available.

⁵ From the available channel impairments described in this deliverable, we have selected the pedestrian with a customize Doppler effect as the most suitable for emulating the basement scenario.



3.5.2 High Level Description of Urban Pedestrian Scenario

Table 4 - Urban Pedestrian Scenario Parameters

| <i>Parameter</i> | <i>Description</i> |
|-----------------------------------|--|
| <i>Received Power</i> | -80 dBm/15kHz |
| <i>Duplex Mode</i> | FDD |
| <i>Downlink/Uplink Bands</i> | Band number 7. |
| <i>Downlink/Uplink Bandwidth</i> | 20 MHz |
| <i>Cyclic Prefix</i> | Normal. |
| <i>Specific TDD configuration</i> | N/A |
| <i>NB-IoT Mode</i> | N/A |
| <i>Number of Tones</i> | N/A |
| <i>Carrier Assignment</i> | 1 Primary Cell (LTE) with 1 Secondary Cell (Downlink) |
| <i>Carrier Setup</i> | N/A |
| <i>Downlink Scheduling</i> | <ul style="list-style-type: none">• Downlink Antenna Configuration: 2x2• Resource Allocation:• Maximum Modulation Coding Scheme Index: 28 (64-QAM) |
| <i>Downlink RB Allocation</i> | 50 RBs |
| <i>Uplink Scheduling</i> | Maximum Modulation Coding Scheme Index: 24 (16-QAM) |
| <i>HARQ</i> | Maximum number of repetitions for data: 4. |
| <i>Connected DRX</i> | Depends on the application category. |
| <i>Impairments</i> | <ul style="list-style-type: none">• Pedestrian Channel Model• AWGN |



4 5G Network Requirements

In the literature, there is a considerable amount of information regarding 5G network requirements. Those resources describe what different applications are expecting from the network in terms of data throughput and delay. However, the purpose of this section is to describe what 5G networks are expected to offer in different scenarios. By indicating what the different applications are expected to cope with, we look at the problem in a fundamentally different manner. If a given application cannot properly operate under a given scenario, it is concluded that the application is not compatible with that scenario.

Table 5, Table 6, and Table 7 describe what the network is expected to offer for urban scenarios and IoT scenarios. They set upper limits and do not consider any market-driven throttling which could be imposed by network operators data plans. Notwithstanding, the user of the Testing Framework can set throttling parameters in the core network of the test. These scenarios can have their network conditions further changed with the use of on-demand per-user QoS sessions created by VPS Engine (see Section 9.7.4).

We have selected these scenarios as we consider them as the most representatives for the applications listed. We also note that connected cars technology is not mature enough at the moment of writing this deliverable. Thus, we cannot properly indicate the expected data rates and latencies.

Table 5 - 5G Network Requirement Urban Scenarios (1/2)

| Scenario | | Virtual Reality | Gaming | Content Distribution Streaming |
|------------|--------------|--|---|---|
| Office | Latency | Low (1 – 10 ms) | Medium (10 – 50 ms) | High (>50ms) |
| | Data Rate | Very high (>1Gpbs) [9] ⁶ DL: 3 Gbps UL: 1.5 Gbps | Medium (50-100 Mbps) DL: 100 Mbps UL: 50 Mbps | High (100 – 1000 Mbps) DL: 25 Mbps UL: 0.1 Mbps |
| | Availability | Low (<95%) | Medium (<95%) | Low (<95%) |
| Pedestrian | Latency | Low (1 – 10 ms) | Medium (10 – 50 ms) | High (>50ms) |
| | Data Rate | High (100 – 1000 Mbps) DL: 500 Mbps UL: 10 Mbps | Medium (50-100 Mbps) DL: 50 Mbps UL: 25 Mbps | Medium (50-100 Mbps) DL: 25 Mbps UL: 0.1 Mbps |
| | Availability | Low (<95%) | Medium (<95%) | Low (<95%) |
| Driving | Latency | High (> 50 ms) | | |

⁶ As mentioned in previous sections the expected upper limit for VR reality is 5.2 Gpbs. However, in the scope of this project, we assume the VR throughput will be limited to Category 14 Release 12 downlink and uplink throughput.



| | | | | |
|-----------------------------------|--------------|--|--|---|
| | Data Rate | Low (<50Mbps) ⁷ DL: 20 Mbps UL: 20 Mbps | | |
| | Availability | Low (<95%) | | |
| <i>Internet Café – Off Peak</i> | Latency | Medium (10 – 50 ms) | Medium (10 – 50 ms) | Medium (10 – 50 ms) |
| | Data Rate | Medium (50-100 Mbps) DL: 100 Mbps UL: 50 Mbps | Medium (50-100 Mbps) DL: 10 Mbps UL: 0.1 Mbps | Medium (50-100 Mbps) DL: 10 Mbps UL: 0.1 Mbps |
| | Availability | Medium (<95%) | Medium (<95%) | Medium (<95%) |
| <i>Internet Café – Busy Hours</i> | Latency | Medium (10 - 50 ms) | High (>50ms) | Medium (10 – 50 ms) |
| | Data Rate | Medium (50-100 Mbps) DL: 100 Mbps UL: 10 Mbps | High (100 – 1000 Mbps) DL: 5 Mbps UL: 0.1 Mbps | High (100 – 1000) DL: 5 Mbps UL: 0.1 Mbps |
| | Availability | Low (<95%) | Low (<95%) | Low (<95%) |

Table 6 - 5G Network Requirement Urban Scenarios (2/2)

| Scenario | | Live Streaming | High Speed Internet |
|-------------------|--------------|--|--|
| <i>Office</i> | Latency | Medium (10 – 50 ms) | Medium (10 – 50 ms) |
| | Data Rate | High (100 – 1000 Mbps) DL: 25 Mbps UL: : 25 Mbps | High (100 – 1000) ⁸ DL: 500 Mbps UL: 100 Mbps |
| | Availability | Low (<95%) | Medium (>95%) |
| <i>Pedestrian</i> | Latency | Medium (10 – 50 ms) | Medium (10 – 50 ms) |
| | Data Rate | Medium (50-100 Mbps) DL: 25 Mbps UL: 25 Mbps | High (100 – 1000) DL: 100 Mbps UL: 50 Mbps |
| | Availability | Low (<95%) | Medium (>95%) |
| <i>Driving</i> | Latency | High (> 50 ms) | |
| | Data Rate | Low (< 50Mbps) ⁹ | |

⁷ For driving scenarios the minimum expected throughput of the network corresponds to the broadband everywhere with a minimum of 20 Mbps. For the time being we assume the mentioned latency and data rates will be available for the different driving scenarios depicted in the previous section.

⁸ Based on category 7,4 Release 11.



| | | | |
|---------------------------------------|--------------|--|---|
| <i>Internet Café – Off Peak</i> | | DL: 20 Mbps UL: 20 Mbps | |
| | Availability | Low (<95%) | |
| | Latency | Medium (10 – 50 ms) | Medium (10 – 50 ms) |
| | Data Rate | Medium (50-100 Mbps) DL: 10 Mbps UL: 10 Mbps | Medium (50-100 Mbps) DL: 100 Mbps UL: 50 Mbps |
| <i>Internet Café – Busy Hours</i> | Availability | Medium (<95%) | Medium (<95%) |
| | Latency | Medium (10 – 50 ms) | Medium (10 – 50 ms) |
| | Data Rate | High (100 – 1000) DL: 5 Mbps UL: 5 Mbps | High (100 – 1000) DL: 100 Mbps UL: 10 Mbps |
| | Availability | Low (<95%) | Medium (>95%) |

Table 7 - 5G Network Requirement IoT Scenarios

| Scenario | | Smart Metering | Patient Monitoring | Smart Grid |
|-------------------|--------------|--|---|--|
| <i>Office</i> | Latency | Extreme High (>10s) | | High (>50 ms) |
| | Data Rate | Extreme Low (<250 kbps) DL: 250 kbps UL: 20 kbps ¹⁰ | | Low (<50 Mbps) DL: 1 Mbps UL: 1 Mbps |
| | Availability | High (>99%) | | High (>99%) |
| <i>Pedestrian</i> | Latency | N/A ¹¹ | Extreme High (>10s) | High (>50 ms) |
| | Data Rate | | Extreme Low (<250 kbps) DL: 20 kbps UL: 20 kbps | Low (<50 Mbps) DL: 1 Mbps UL: 1 Mbps |
| | Availability | | High (>99%) | High (>99%) |
| <i>Driving</i> | Latency | N/A | N/A ¹² | High (>50 ms) |
| | Data Rate | | | Low (<50 Mbps) DL: 250 kbps |

⁹ For driving scenarios the minimum expected throughput of the network corresponds to the broadband everywhere with a minimum of 20 Mbps. For the time being we assume the mentioned latency and data rates will be available for the different driving scenarios depicted in the previous section.

¹⁰ We assume smart meters with single tone support.

¹¹ We assume Smart Meters are static and will not be moved over their lifetime.

¹² Our main assumption for patient monitoring will employ NBIOT which does not consider handovers. Thus, we consider Patient monitoring as static or quasi-static rendering this case not applicable.



| | | | | |
|------------------------|--------------|--|--|---|
| | Availability | | | UL: 250 Kbps Medium (>95% - <99%) |
| <i>Internet Café</i> | Latency | Extreme High (>10s) | | High (>50 ms) |
| | Data Rate | Extreme Low (<250 kbps) DL: 250 kbps UL: 20 kbps ¹³ | | Low (<50 Mbps) DL: 1 Mbps UL: 1 Mbps |
| | Availability | High (>99%) | | High (>99%) |
| <i>Warehouse</i> | Latency | Extreme High (>10s) | Extreme High (>10s) | High (>50 ms) |
| | Data Rate | Extreme Low (<250 kbps) DL: 50 kbps UL: 10 kbps | Extreme Low (<250 kbps) DL: 250 kbps UL: 20 kbps | Low (<50 Mbps) DL: 250 kbps UL: 250 kbps |
| | Availability | High (>99%) | High (>99%) | Low (<95%) |
| <i>Outdoor Sensors</i> | Latency | Extreme High (>10s) | | High (>50 ms) |
| | Data Rate | Extreme Low (<250 kbps) DL: 100 kbps UL: 10 kbps | | Low (<50 Mbps) DL: 250 kbps UL: 250 kbps |
| | Availability | High (>99%) | | Low (<95%) |
| <i>Home Basement</i> | Latency | Extreme High (>10s) | | High (>50 ms) |
| | Data Rate | Extreme Low (<250 kbps) ¹⁴ DL: 100 bps UL: 100 bps | | Extreme Low (<250 kbps) ¹⁵ DL: 10 kbps UL: 10 kbps |
| | Availability | High (>99%) | | Low (<95%) |

¹³ We assume smart meters with single tone support.

¹⁴ We consider the worst case scenario where the signal strength is so low that several transmissions of each packet are required. Thus, an extreme low rate both in downlink and uplink.

¹⁵ We consider the minimum data rate available in LTE-M which is roughly 10 kbps.

5 Triangle Mark Definition

Measurements, Key Performance Indicators (KPIs) and Metrics are the three main concepts that define the Triangle mark.

Measurement is a value discovered by measuring, that corresponds to a property of something. The measurements come from the logs that can be collected by the Triangle Testing Framework. For example, the instantaneous current in Amperes measured by a Power Meter is an example of measurement in TRIANGLE.

Key Performance Indicator is a quantitative evaluation of a criteria that a product (i.e., device or App) must meet before release. A KPI is computed from a set of measurements. For example, energy usage while an App is in active state is a KPI computed from current consumption measurement.

Metric is a categorization of the KPIs from a user satisfaction perspective. The collection of metrics is displayed as a spiderweb/radar (see Figure 1). In the case of App testing, each App Category has a reference “certification values” for each metric

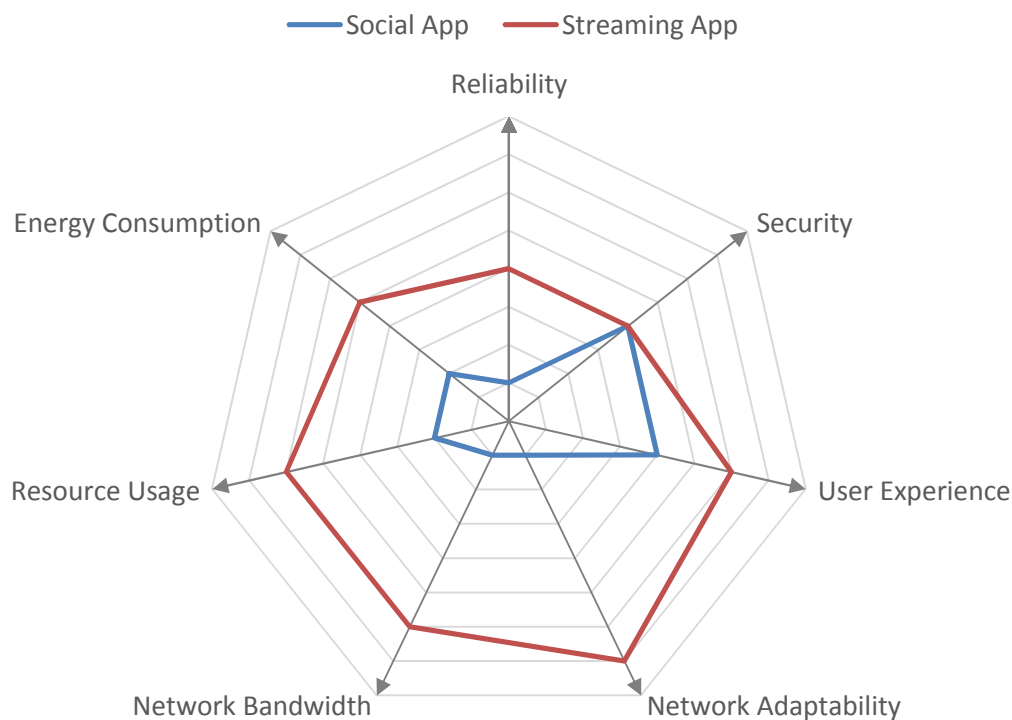


Figure 1 - Example of Spider web for Applications

The Triangle mark can be computed from the metrics following the process described in Figure 2.

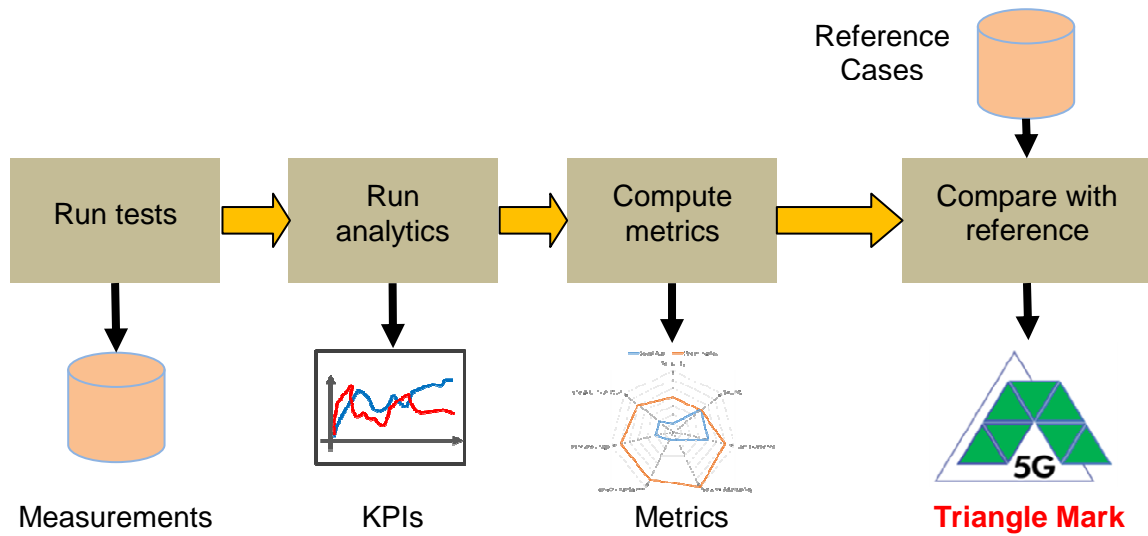


Figure 2 - Triangle Mark Certification Process

The Reference Cases are the combinations of the 5G use cases (Section 2) and the 5G testing scenarios (Section 3). The Triangle Testing Framework applicant must select the reference case for a Triangle certification.

The details of the Reference Cases will be described in the Deliverable D2.2 of this project.

The following sections gather the result of the preliminary analysis of the metrics and KPIs which are to be used for the definition of the Triangle mark.

5.1 Potential Metrics of Interest for Applications

5.1.1 Reliability

This metric reflects the probability of the App operating without failure while in a specified environment over a set duration of time.

The following KPIs are identified:

- Stability (Ability not to crash or freeze at any time while running on the device)
- Auto recovery after fail
- Ability to manage corruption or loss of its data files
- Data losses

5.1.2 Energy Consumption

This metric quantifies the actual energy demand made by the App which impacts on the device battery life.

The following KPIs are identified:

- Consumption in active state
- Consumption in background



5.1.3 Network resources usage

This metric quantifies the ability of the app to have fine-grained control over its usage of network resources.

The following KPIs are identified:

- Downlink data usage in active mode
- Uplink data usage in active mode
- Downlink data usage in background
- Uplink data usage in background

5.1.4 User Experience

This metric is a measure of the user's satisfaction with the App. Although User Experience (UX) is perceived as subjective metric, it is the key measure that counts for the users of a service.

The UX KPIs are tightly related to the type of application. As preliminary study the following groups are identified: Social, Streaming, Virtual Reality and Augmented Reality.

5.1.4.1 Social App

The following KPIs are identified for Social Apps:

- Time to log in
- Time to post content
- Time to download content
- Playback experience (e.g., picture freezing, video quality):

5.1.4.2 Streaming App

The following KPIs are identified for Streaming Apps:

- Time to log in
- Time to search a video / audio title
- Playback experience (e.g., picture freezing, video quality)

5.1.4.3 Virtual Reality App

The following KPIs are identified for Virtual Reality Apps:

- Response Time (i.e., time to detect user interaction with the system)
- Time to load and display 3D environment
- Frames per second
- Data Usage

5.1.4.4 Augmented Reality App

The following KPIs are identified for Augmented Reality Apps

- Response Time (i.e., time to detect user interaction with the system)
- Data Usage



5.1.5 Device resources usage

This metric quantifies the ability of the app to have fine-grained control over its usage of the device resources.

- In-use resources
- Background resources
- Effective resource release

5.1.6 Network adaptation

This metric quantifies the ability of the App to determine the state of the network connectivity and react accordingly.

- Ability to handle network low bandwidth
- Ability to handle network delay
- Ability to handle network connection losses
- Ability to compress the content
- Ability to adapt streaming quality to the network conditions (e.g., video streaming apps)
- Ability to upload content only when the device is connected to Wi-Fi
- Ability to sync (or not) depending on specific criteria such as network availability, or time interval
- Cache control
- Content pre-fetching and expiration

5.1.7 Security

This metric resides out of the scope of the TRIANGLE project and has been added only for reference.

5.2 Potential Metrics of Interest for Devices

5.2.1 Data Performance

This metric gathers the related network aspects which may impact on the quality of experience of applications running on the device under test.

- Throughput in different configurations: downlink, uplink, TCP, UDP, small and large packets
- Delay, packet loss rate, consecutive packets lost and jitter at traffic loads below the network capacity

5.2.2 Radio Performance

This metric gathers the related radio frequency aspects which may impact on the quality of experience of applications running on the device under test.

- Sensitivity
- Adjacent channel selectivity



- Non-adjacent channel selectivity
- Maximum input signal
- Maximum tolerable signal

5.2.3 Energy Consumption

This metric gathers the related energy usage aspects under different conditions which may impact device's user satisfaction:

- Idle state
- CS and PS voice call
- Video call
- Video camera streaming broadcast
- Video camera display (i.e., for augmented reality Apps)
- Network assisted navigation
- Full buffer transmission and reception

5.2.4 Quality of experience in reference Apps

This metric is a measure of the user's satisfaction with widely used App.

The UX KPIs are tightly related to the type of application. As preliminary study the following groups are identified: Social, Streaming, Virtual Reality and Augmented Reality.

A preliminary analysis of the applications is introduced in Section 9.3. However, the selection of the reference App will be undertaken and justified in the scope of the Deliverable D.2.3.

5.3 Potential Metrics of Interest for IoT Devices

Most of the IoT devices are expected to run very simple applications. In TRIANGLE we consider the IoT device, the OS, and its app as a single entity.

5.3.1 Reliability

This metric reflects the probability of the IoT operating without failure while in a specified environment over a set duration of time.

The following KPIs are identified:

- Stability (Ability to not crash or freeze at any time while running on the device)
- Auto recovery after fail
- Ability to manage corruption or loss of its data files
- Network unavailability

5.3.2 Radio Performance

This metric gathers the related radio frequency aspects which may impact on the quality of experience of the service running on the IoT device under test.

- Sensitivity



- Adjacent channel selectivity
- Non-adjacent channel selectivity
- Maximum input signal
- Maximum tolerable signal
- Multiple antenna operation

5.3.3 Energy Consumption

This metric gathers the related energy usage aspects under different conditions which may impact device's user satisfaction:

- Idle state
- Active state
- Data transmission
- Protocol Operations (such as HARQ or Blind repetitions)

5.4 From the Metrics to the Triangle Mark

In order to aggregate the different KPIs into a single value representative of the specific area of interest (energy consumption rather than quality of experience) there is the need of a combining mathematical formula. Such formula is what is called "Metric" in the scope of the TRIANGLE project. A metric is the value displayed on the axis of the spiderweb diagram previously mentioned.

A metric can be generally defined as:

$$M_n = \Phi_n(\{KPI_j^n\}, \{\underline{KPI}_j^n\}, \{\beta_k\})$$

Where:

- $\Phi_n(.)$ is a formula specific for metric M_n
- $\{KPI_j^n\}$ is the set of measured KPIs for metric M_n
- $\{\underline{KPI}_j^n\}$ is a set of reference values for the KPIs. Depending on the use in the formula they can be, min, max, expected, normalization values or other
- $\{\beta_k\}$ is a set of parameters for the formula

Once all the metrics for a specific category have been computed, there is the need of a further aggregation step before being able to produce the Triangle Mark. One possibility for aggregating all the metric together is for example a weighted linear combination. Such combination is still subject to further studies, because it depends how the metrics will be in the end defined.

An example of Triangle Mark can be computed as (as an example):

$$T\text{-Mark} = \sum w_i * (M_i - \underline{M}_i)$$

Where

- M_i is a considered metric.
- \underline{M}_i is a reference or normalization value.



- w_i is a weighting coefficient that should put the considered metric with the others.

Such score should be eventually quantized into a limited number of “colors” or human-readable categories (e.g. 5G-ready, or excellent etc.).

Determining the precise values for the metrics and coefficients requires experimentation with the tools available in the Testing Framework. The outcome of that task will be reflected in the Deliverable D2.2 of this project.

5.5 Internal Evaluation candidate for Triangle Mark

As mentioned in Section 2.10 TRIANGLE will use the BlueEye wearable video designed for the emergency first responder sector as a way to internally validate the Triangle Testing Framework. The BlueEye is an IoT device with the following features:

- HD video camera integrated to safety glasses
- H264 encoding in hardware
- 1080p/720p HD Color CMOS Image Diagonal 110 +/-5 degree wide angle Belt mounted LTE power pack
- LTE Modem - FDD Category 4 (LTE Bands 1, 3, 5, 7, 8, 20 (Euro))
- 49 Watt/Hour Power Pack (replaceable)

The key questions for testing are what are the relevant axis as per (Figure 1) for the BlueEye and what are the measured values and how do these relate to a relevant benchmark.



6 Testing Framework User Profiles

The purpose of this section is to provide a high level description of the different user profiles which will use the Triangle Testing Framework.

The four main user profiles identified are: (i) application developer, (ii) device developer, (iii) researcher and (iv) mobile operator and service operator.

These profiles will play an important role in defining the testing scenarios, the different potential metrics categories in the Triangle Mark (Section 5) and the required list of measurement capabilities of the Triangle Testing Framework (Section.8).

6.1 App Developer

These pure software personalities are the largest target population for TRIANGLE. These are usually start-up companies who wish to develop an app based on a great idea and need platforms to validate its functionality and its performance under challenging radio conditions.

The app developer, not being a telecommunication engineer, typically does not care about the network details and radio propagation challenges. The developer typically assumes the wireless connection is a reliable data pipe with characteristics similar to a wired one. TRIANGLE will provide a framework to test the impact of realistic data network capability on the app as well as the app impact on the network resource usage, making possible to provide insight on how the App uses the device resources and battery.

Thanks to the Triangle Testing Framework App Developers will be able to have clear insights on the energy performance of their own code.

6.2 Device Developer

Device manufacturers will have a more general system performance level interest in the Triangle Testing Framework to understand the capability of the overall device compared to other reference devices.

Today, the number of smartphone manufacturers is rather limited, but with the upcoming Internet of Things (IoT) and device variety, the numbers to grow rapidly. The skill and knowledge of these device makers is also changing from being a fully integrated in-house developer (with all components in house) towards a more system level integrator type that relies on modules and chipsets from external suppliers. This type of outsourcing, combined with the strict energy requirements of IoT, make TRIANGLE a powerful ally for understanding the real capabilities of the devices in terms of energy saving.

6.3 Mobile Network Operator and Service Operator

While primary targets for testing and certification are the device manufacturers and App developers, the project also wants to provide MNOs with a fully controlled, realistic sandbox where to test advanced network components and configurations. This type of setup is not new to MNOs.

As a matter of fact some of the major operators have similar testbeds in their labs. Although there is wide interest among operators to understand the impact of network configurations on the performance of mobile devices and the QoE of mobile apps, only few major actors can afford it. When available, the functionality may also be limited from a probing perspective.



6.4 Researcher

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

7 Testing Framework Use Cases

This section describes the set of possible sequences of interactions between the Triangle Testing Framework (i.e., the system) and its users (i.e., app developer, device maker, researcher or MNO) in a particular environment and related to a particular goal.

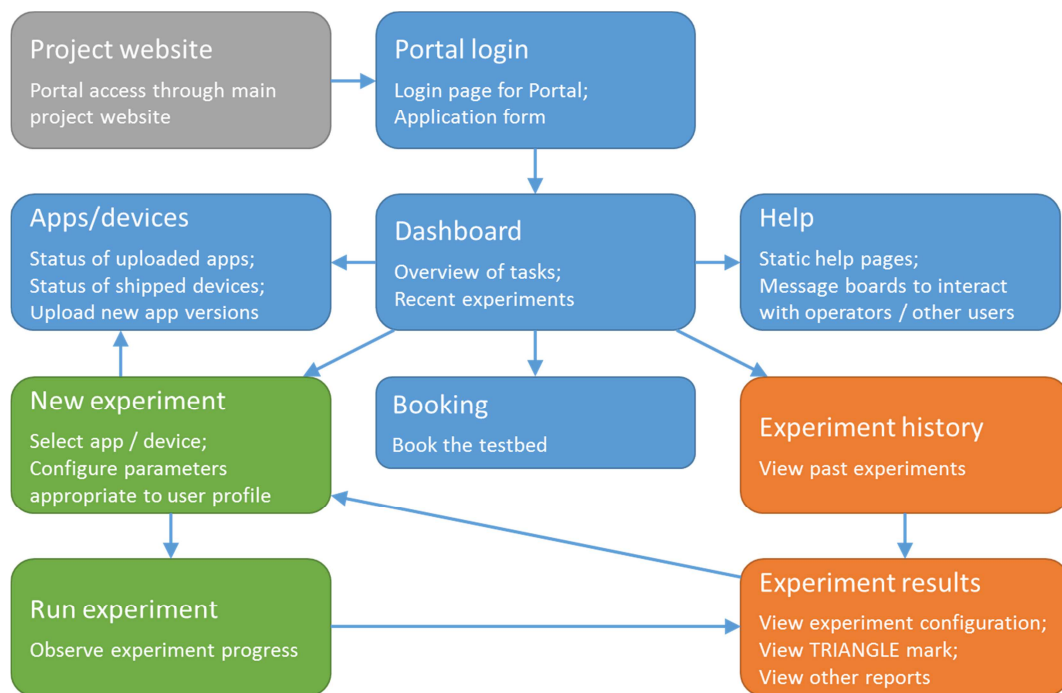


Figure 3 - Experiment Portal organization and user flows [D6.2]

Figure 3 shows the organization of the Experiment Portal, which is the interface to the system, and supports the different user flows required.

The main user flows identified between the user and the system are:

- Application for Admission
- Booking the Testing Framework
- Configuring a new Certification test
- Configuring a new Experiment test
- Configuring a test from an existing one
- Conducting a test
- Analysing the test results

These flows are described more precisely in Section 11 (Appendix 1), but we provide an informal overview here, with the rationale behind each user flow.

The Experiment Portal (just Portal for short) which users access to perform these user flows is a web portal separated from the project website. Although it can be accessed from the website, the Portal requires specific credentials. There will be a web form available in the



Portal, so that new user can apply to request access. These applications will be reviewed using an appropriate process by the testbed operators.

Once a user has logged into the Portal, a dashboard page shows the available user tasks, such as starting a new experiment, as well as a summary of recent and relevant activity, e.g. recent experiments or system notices. In order to use the Testing Framework facilities, the first step would be booking it for a particular time slot. This guarantees exclusive access to Testing Framework equipment that does not support multiple concurrent users.

To execute an experiment, the user has to fill in the required configuration. This process must be tailored for the different user profiles, because the information required for an application test is significantly different from the one required from a NMO, for instance. In addition, we distinguish between two types of experiments: certification tests and experiment tests. The former have a fixed set of parameters and requirements, and are the ones leading to the Triangle Mark. The latter enables the user to perform more free form experiments, with a wider array of configurable parameters.

The configuration of a new experiment includes a few noteworthy inputs. For instance, app developers must provide the file that contains the app under test, and device makers must select a device that they previously shipped to the Testing Framework facilities. To help with these tasks there is also a separate section of the website devoted to managing uploaded apps and shipped devices. For instance, app developers can upload different version of their apps, and select one during test configuration.

For certification tests, app developers also need to provide additional information in order to perform the pre-defined set of tests and measure the relevant KPIs for the Triangle Mark. This is discussed later in this section.

When the booked timeslot is reached, the user can carry out a previously configured experiment. The user can then observe the progress of the experiment, or keep it running unattended.

When the experiment is completed, users can review the results obtained, which depend on the type of test carried out. For instance, the Triangle Mark is only produced for certification tests. The results include reports based on the measured KPIs, and raw data from each of the measurement probes.

Users can also review past experiments, to check which experiments have already been performed, their configurations, and the results obtained. These past experiments can be used as the starting point for a new experiment. That is, instead of starting from a blank configuration, the new experiment will have a complete configuration that can then be tweaked to perform a similar experiment with slightly different parameters. For instance, this is useful to create an experiment for a new version of an app under test.

Finally, the Portal will provide help for the users in the form of static pages and message boards (or similar) for communicating with the Testing Framework operators or other users. Help will also be available in a context sensitive fashion, e.g. showing links to help topics relevant to experiment configuration when creating a new one.

7.1 App user flows and KPIs

In order to provide a standardized Triangle Mark across apps of the same category, app developers must provide additional information when creating a certification test. On the one hand, they must provide the app user flows for carrying out each of the supported application requirements, e.g. sending a photo in a messaging app. On the other hand, they must declare



how each relevant KPI is going to be measured on these requirements, e.g. the time taken to send the photo.

For each app user flow, the app developer will provide an ordered list of user action that must be performed on the UE running the app. These user actions must include which element on the screen the app user is interacting with, e.g. a button or a list, and which action is being performed, e.g. a single tap or a swipe. This list will serve as directions to replicate the app user flow in an automated manner on a wide range of UEs.

Depending on each app requirement, the app developer may need to declare how a particular KPIs is going to be measured in that particular app. In some cases this will require small changes in the app code in order to provide the appropriate hook or value. We anticipate two complementary ways of providing this information, depending on the particular KPI.

For KPIs that can be derived from the user actions carried out in the test and the observable controls in the screen, the app developer must match KPIs conditions, e.g. “start of image upload” and “end of image upload”, to certain user actions in the app user flow, e.g. “pressing the send button”, or to the occurrence of a particular element in the screen, e.g. the “image thumbnail” appears.

Some KPIs require information which cannot be readily acquired in this manner, e.g. the current bitrate of a video player. Therefore, the developer will be required to instrument the application to provide the required information in an appropriate manner to be detected and consumed by the Testing Framework. The means of providing this information will be defined so as to minimize the developer effort and execution overhead.



8 Testing Framework Measurement Capabilities

8.1 Power Consumption

The system shall have the ability to measure the instantaneous power consumption of the device under test in different usage and network conditions with the following accuracy:

- 1 A Current range: 0.1% + 0.2 mA
- 0.02 A Current range: 0.1% + 2.5 μ A
- Response time: 1 ms

8.2 Data Traffic Performance

This section describes the data traffic performance indicators that the system shall be able to measure:

- Application layer data throughput [10] with one second resolution
- Application layer one-way delay [11] with one SDU resolution
- Application layer one-way jitter [12] one SDU resolution
- Application layer one-way packet loss rate [13] one SDU resolution
- Application layer one-way consecutive packets lost [14] resolution one SDU resolution
- Elapsed time with one millisecond resolution between consecutive received packets at the application layer of the receiver data endpoint. This indicator is also called Application layer SDU inter-arrival time.

8.3 Radio Performance

- The system shall measure the Device receiver sensitivity.
- The system shall measure the Device adjacent channel selectivity.
- The system shall measure the Device non-adjacent channel selectivity.
- The system shall measure the Device receiver maximum input signal (i.e., UE is capable of decoding an on-channel input signal with maximum required power).
- The system shall measure the Device receiver maximum tolerable signal (i.e., UE tolerates co-channel OFDM signal at 0dBm and still recover and operate correctly when the co-channel is removed).

8.4 Device System Information

The system shall have the ability to capture the following system information parameters as from the Device under test.

- Geo-location position
- Geo-location accuracy



- Active data connection (i.e., Wi-Fi or Mobile)
- Application layer total bytes received by the network interfaces
- Application layer total bytes sent by the network interfaces
- CPU usage

8.5 Device Mobile Data Information

The system shall have the ability to capture the following information parameters as they are reported by the Device under test while using the mobile data connection:

- SNR
- RSRP
- RSRQ
- CQI
- RI
- PMI
- Cell-Id
- TAC
- MCS

The parameters above can be extracted wither form the device itself or from the eNodeB emulator.

At this date only Android OS provides public API to extract the information in the list above.

8.6 Device Wi-Fi Information

The system shall have the ability to capture the following information parameters as they are reported by the Device under test while using the Wi-Fi connection:

- Wi-Fi BSSID
- Wi-Fi ESSID
- Wi-Fi RSSI
- Wi-Fi physical data rate. This is the binary speed in bit/s (i.e., how fast the device can write bits into the air media) which results from the active physical level configuration: modulation, coding rate, bandwidth, spatial streams and guard interval (short or long).
- Wi-Fi channel
- Neighbours Wi-Fi access points

The parameters above can be extracted either form the device itself or from the WLAN Access Point.

At this date only Android OS provides public API to extract the information in the list above.



9 Testing Framework High Level Requirements

9.1 Devices Supported

The goal of this section is to identify the main existing devices manufacturers in the industry in order to be considered as reference handsets for application testing in the Triangle Testing Framework. Several market forecast have been published and it is difficult to provide definitive figures, however the overall scoring, which is relevant for TRIANGLE, is similar in all reports.

9.1.1 Top five smart phone manufacturers

Table 8 compiles the top five smart phones manufacturers in the first quarter of 2016 according to the report in [15].

Table 8 - Top Five Smart Phones Manufacturers Market Share (16Q1) [15]

| <i>Name</i> | <i>Market Share (16Q1)</i> |
|----------------|----------------------------|
| <i>Samsung</i> | 24.5 % |
| <i>Apple</i> | 15.3 % |
| <i>Huawei</i> | 17.4 % |
| <i>OPPO</i> | 7.3 % |
| <i>Vivo</i> | 4.3 % |
| <i>Others</i> | 42.3 % |

Xiaomi and Levono are not in the list because were relegated by OPPO and Vivo in the first quarter of 2016. However, they could be considered in the TRIANGLE project as reference handsets because the market shares usually fluctuate every quarter and could appear again in the top list in future quarters. Actually, nine of the twelve largest device manufacturers are Chinese and they share one quarter of the world share.

Narrowing the coverage of the analysis to five European Union Countries (Germany, Italy, UK, France and Spain) shows that the ten most used smart phones are either Samsung or Apple. LG is found at eleventh position and Huawei at thirteenth [16].

9.1.2 Top five tablet manufacturers

Table 9 compiles the top five tablet manufacturers in the first quarter of 2016 [15].

Table 9 - Top Five Tablets Manufacturers Market Share (16Q1) [15]

| <i>Name</i> | <i>Market Share (16Q1)</i> |
|----------------|----------------------------|
| <i>Apple</i> | 25.9 % |
| <i>Samsung</i> | 15.2 % |
| <i>Amazon</i> | 5.7 % |
| <i>Lenovo</i> | 5.5 % |
| <i>Huawei</i> | 5.2 % |

*Others*

42.3 %

Both Apple and Samsung saw a significant decline on the last year over year growth whereas Amazon share has noticeably increased.

Narrowing the coverage of the analysis to five European Union Countries (Germany, Italy, UK, France and Spain) shows that the ten most used tablets are either Samsung or Apple. Amazon is found at eleventh position [16]

9.1.3 Top five wearables manufacturers

Table 10 compiles the top five wearable manufacturers in the first quarter of 2016 [15].

Table 10 - Top Five Wearables Manufacturers Market Share (16Q1) [15]

| <i>Name</i> | Market Share (16Q1) |
|----------------|----------------------------|
| <i>Fitbit</i> | 24.5 % |
| <i>Xiaomi</i> | 19.0 % |
| <i>Apple</i> | 7.5 % |
| <i>Garmin</i> | 4.6 % |
| <i>Samsung</i> | 3.6 % |
| <i>Others</i> | 40.8 % |

Regarding wearables it is noteworthy that the worldwide market has leaped 171.6 % in 2015 mostly due to the popularity of fitness trackers and the Apple Watch.

9.2 Operating Systems

The goal of this section is to identify the main existing operating systems (OS's) for smart phones, tablets and IoT devices.

In terms of the Mobile OS's, Table 11 compiles the OS with relevant participation (market share > 0.1 %) in the industry [17].

Table 11 - Mobile OS and Market share

| <i>Name</i> | Company | Market Share (16Q1) | Market Share (15Q1) |
|----------------------|-----------------|----------------------------|----------------------------|
| <i>Android</i> | Google Inc. | 84.1 % | 78.8 % |
| <i>iOS</i> | Apple Inc. | 14.8 % | 17.9 % |
| <i>Windows Phone</i> | Microsoft | 0.7 % | 2.5 % |
| <i>BlackBerry 10</i> | BlackBerry Ltd. | 0.2 % | 0.4 % |

Based on the current market share and the inter-year trend, Android and iOS are the ones selected for the Triangle Testing Framework.



In the case of Apple iOS, IPA (iPhone application archive) is needed to automate and integrate the reference Apps in the Triangle Testing Framework. The IPA can be only provided by the App developer (e.g., Google Inc, Facebook, etc), which does not seem a feasible path ahead due to privacy concerns. Even though Apple (as Device Maker) applying for Triangle certification is not likely, a Mobile Operator may apply for the Triangle certification and require iOS reference App benchmarks on the Apple device in different 5G scenarios. In such a case, the Mobile Operator will have to request to the App developer for the IPA for further integration of the App in the test bed.

While the matter is clear with Mobile OS's, IoT is a new field of specialization and specialized IoT OS's are new and limited because the field is new and there are still few IoT specialists.

Mobile OS's are part of the IoT, they will probably will be the main interface in the future [18]. However, this heavy OS's (in terms of RAM/ROM and power consumption) will not meet the power-critical requirements of lot of things that are expected to be connected to the Internet such as wireless network sensors.

A preliminary analysis of the IoT OS's is introduced in section 12. However, the selection of the complete analysis will be undertaken and justified in the scope of the Deliverable D.2.3.

9.3 Reference Apps (for Device Testing)

The goal of this section is to identify the top mobile apps which currently reach the app audience. It is important to note that reports should be analysed carefully as App users have unique regional preferences. The analysis will provide supporting information in order to select the most convenient reference applications in the TRIANGLE project for device testing.

Before considering the Apps themselves, the Apps platforms need to be considered. The main App platforms are:

Table 12 - Main Apps platforms

| Rank | App Name |
|-------------|-----------------|
| 1 | Google Play |
| 2 | iOS |

There are many reports on this matter and results depend on the geographic region. Table 13 is an example from [19] which compiles overall audience (market share) in the US.

Table 13 - Top Ten Apps in US (January, 2016) [19]

| Rank | App Name | % Market Share |
|-------------|--------------------|-----------------------|
| 1 | Facebook | 78.4 % |
| 2 | Facebook Messenger | 64.1 % |
| 3 | YouTube | 61.1 % |
| 4 | Google Play | 51.0 % |
| 5 | Google Search | 50.2 % |
| 6 | Google Maps | 48.7 % |



| | | |
|----|---------------|--------|
| 7 | Gmail | 44.8 % |
| 8 | Pandora Radio | 41.4 % |
| 9 | Instagram | 39.0 % |
| 10 | Amazon Mobile | 33.4 % |

Another report from [20] provides a report of the worldwide download top Apps in 2015, and shows slightly different ranks.

Table 14 - Top Ten Apps Worldwide (2015) [20]

| Rank | App Name |
|-------------|---------------------|
| 1 | WhatsApp Messenger |
| 2 | Facebook Messenger |
| 3 | Facebook |
| 4 | Instagram |
| 5 | Clean Master |
| 6 | 360 Mobile Security |
| 7 | Skype |
| 8 | YouTube |
| 9 | UC Browser |
| 10 | Snapchat |

Another report [20] that only takes into account Google play (Google Play Store) downloads estimates the top Apps by all-time worldwide as provided in the next table.

Table 15 - Top Ten Apps Worldwide (2015) [20]

| Rank | App Name | Company |
|-------------|----------------------|----------------|
| 1 | Facebook | Facebook |
| 2 | WhatsApp Messenger | Facebook |
| 3 | Facebook Messenger | Facebook |
| 4 | Instagram | Facebook |
| 5 | Clean Master | Cheetah Mobile |
| 6 | Skype | Microsoft |
| 7 | Line | Line |
| 8 | Viber | Rakuten |
| 9 | Twitter | Twitter Inc. |
| 10 | Flashlight by Surpax | Surpax |



The analysis of Apps should also consider the category or classification of the Apps. In the analysis consider for the project the following categories have been considered: games, social, music & audio, and media & video. It has been identified [20] that the three top music & audio Apps are:

Table 16 - Top Ten Apps Worldwide (2015) [20]

| <i>Rank</i> | <i>App Name</i> | <i>Company</i> |
|-------------|-----------------|----------------------|
| 1 | Shazam | Shazam Entertainment |
| 2 | Spotify | Spotify |
| 3 | PandoraRadio | Pandora |

Finally, it is also worth of consideration those services that account for most of the broadband usage. According to some reports [21] they continue to grow, even though they are not mostly used in smart phones nowadays. This might change in the future when, 5G networks, with increase network efficiency and per-user throughput, get deployed.

Table 17 - Top Ten Services Broadband Usage (2015) [20]

| <i>Rank</i> | <i>Service Name</i> | <i>% Share</i> |
|-------------|---------------------|----------------|
| 1 | Netflix | 37.1 % |
| 2 | YouTube | 17.8 % |
| 3 | HTTP | 6.1 % |
| 4 | Amazon Video | 3.1 % |
| 5 | iTunes | 2.8 % |
| 6 | BitTorrent | 2.7 % |
| 7 | Hulu | 2.6 % |
| 8 | Facebook | 2.6 % |
| 9 | MPEG-Other | 2.1 % |
| 10 | SSL-Other | 1.3 % |

Other trendy applications which will surely impact future reports are the social media live streaming apps such as Livestream and Periscope. These will be also considered in TRIANGLE as reference applications for device testing because they incorporate specific live streaming services set of requirements.

9.4 Radio Access Technologies (RATs)

9.4.1 Wi-Fi Access

The system shall have the ability to coordinate Wi-Fi access points and control the following parameters:



- Operating Channel
- Transmission Power
- Channel Bandwidth
- Radio Status (On/Off)

9.4.2 3GPP Access

The system shall have the ability to emulate a mobile data connection access with the following parameters:

Supported formats

- LTE/LTE-A/NB-IoT

Basic Cell Configuration

- Duplex Mode: FDD and TDD
- DL Bandwidth: 1.4MHz, 3MHz, 5MHz, 10MHz, 15 MHz and 20MHz
- UL Bandwidth: 1.4MHz, 3MHz, 5MHz, 10MHz, 15 MHz and 20MHz
- Mandatory Frequency Setting Method: EARFCN. The system shall support defining the operating frequency by selecting the EUTRA Absolute radio-frequency channel number. Other methods to select the operating frequency might be available.
- LTE Bands supported in FDD: 1 to 32 (excluding 15 and 16), 252 and 255
- LTE Bands supported in TDD: 33 to 44
- TDD Frame Configuration: 0 to 6 (Release 8). Additional frame configurations as defined in later releases is optional.
- TDD Special Subframe Configuration: 0 to 8 (Release 8) and 9 (Release 11).

The details of the mobile data connection parameters to be provided by the Testing Framework are in Section 13 (Appendix 3).

9.5 RF Channel Conditions

The Triangle Testing Framework shall have the ability to emulate different channel conditions in terms of signal levels, fading profiles, and noise and interference levels.

Table 18 extracted from 3GPP TR 37.901 [10] specifies de facto conditions to challenge the higher layers, and also cover the vast majority of 5G usage scenarios experienced in field tests as described in Section 2.

Table 18 - Test Points for LTE [10]

| Propagation Condition | SNR | Justification |
|------------------------------|-----------------|--|
| Static | No interference | To check that upper-layers do not constrain data throughput |
| EPA5 | 20 dB | To exhibit large TBS variations (see clause 5.5.4.3) and very common |



| | | |
|--------|-------|--|
| | | scenarios for high-data rate requiring processing capability |
| EVA5 | 10 dB | EVA occurs frequently in deployments |
| EVA70 | 20 dB | Adds EVA70, high SNR coverage which is common in low frequency(<1GHz) band networks |
| EVA200 | 20 dB | Covers high Doppler, high SNR scenario which is common in high frequency(≥ 1 GHz)band networks |
| ETU70 | 0 dB | Fast variations and most common high-dispersion case |
| ETU300 | 0 dB | A high BLER scenario may trigger higher layer retransmissions, and also addresses the high speed scenario in the work item objective |

The system shall support the emulation of the following propagation conditions:

- EPA5
- EVA5
- EVA70
- EVA200
- ETU70
- ETU 300

9.6 Core Network (EPC)

The Triangle Testing Framework should include the following elements of a functional and standard EPC (Evolved Packet Core):

- MME (Mobility Management Entity). The MME is the entity in charge of managing security functions, tracking, paging and mobility procedures, among other functions established in 3GPP TS 23.401 [22] and 3GPP TS 36.300 [23]. MME is also involved in bearer activation and deactivation procedures. The MME should include the following standard interfaces: S1-MME, S11, S10, S6a, S13, S3, SBc, SGs, S102, M3, Sm and support the basic functionalities specified in 3GPP TS 23.401 [22] and 3GPP TS 36.300 [23].
- SGW (Serving Gateway). The SGW is the gateway that terminates the EPC towards the E-UTRAN. For each UE associated with the EPS, at any given point in the time there will be a single SGW hosting the following functions, defined in 3GPP TS 23.401 [22] and 3GPP TS 36.300 [23]. The SGW should include the following interfaces: Gx, Rx, S9, Gxx and the basic functionalities specified in 3GPP TS 23.401 [22] and 3GPP TS 36.300 [23].
- PGW (Packet Data Network Gateway). The PGW is the gateway that terminates the SGi interface towards the PDN (Packet Data Network). The PGW should include the following interfaces: S5-c, S5-u, S8-c, S8-u, SGi, S2a, S6b, Gx and the basic functionalities specified in 3GPP TS 23.401 [22] and 3GPP TS 36.300 [23].
- PCRF (Policy and Charging Rules Function). The PCRF is in charge of managing the service policy and sending QoS setting information for each user session and accounting rule information. The PCRF should include the following interfaces: Gx, Rx, S9, Gxx, and the basic functionalities specified in 3GPP TS 23.002 [24] and in 3GPP TS 23.401 [22].



- HSS (Home Subscriber Server). The HSS is the central database for all subscriber related data in the network. It contains subscriber-specific data such as International Mobile Subscriber Identity (IMSI), Mobile Station International ISDN Number (MSISDN), subscribed APN, priority indication, etc. The HSS should support the following interfaces: S6a, Zh, Cx and the basic functionality specified in 3GPP TS 23.002 [24] and in 3GPP TS 23.401 [22].
- The EPC should support an interface for the management, configuration and control of the components of the EPC.

The EPC should also provide the following features:

- Management and configuration interface for all the components
- Programming API to automate their remote management and configuration
- Traffic sniffing on all the interfaces of the network elements
- Support the definition of positive and negative behaviors
- Remote introduction of traffic impairments in the transport interfaces such as packet loss, delay, jitter, corruption and duplication in the data traffic
- Definition of policy rules for traffic prioritization

9.6.1 Mobility

The Triangle Testing Framework shall have the ability to emulate different mobility scenarios.

- Intra-System Handover
- Inter-System Handover
- Roaming

9.6.2 Cell Load

The Triangle Testing Framework shall have the ability to emulate different cell loads.

- The system shall support the allocation of a specific number of Physical Resource Blocks (PRBs) to simulate different load conditions of the cell.
- The system shall support the simulation of virtual allocations of the non-assigned resources to virtual users in order to keep full downlink occupancy.

The Triangle Testing Framework shall have the ability to generate application layer traffic with the following characteristics:

- Protocol layers: IPv4 and IPv6
- Transport layers: UDP and TCP
- Single and multiple streams TCP
- DSCP marking
- Application layer SDU size: Constant, Uniform, Exponential, Pareto, Cauchy, Normal, Poisson, Gamma, Weibull
- Application layer SDU inter-departure time: Constant, Uniform, Exponential, Pareto, Cauchy, Normal, Poisson, Gamma, Weibull



- Traffic bursts with the following statistical distributions for the On and Off periods: Constant, Uniform, Exponential, Pareto, Cauchy, Normal, Poisson, Gamma, Weibul

9.6.3 Dual Connectivity

The Triangle Testing Framework shall have the ability to emulate different scenarios with Dual Connectivity. Within the scope of the TRIANGLE project the Testing framework shall be able to support DC between 3GPP radio access nodes and between 3GPP and non-3GPP radio access nodes. In particular:

- Establish a DC connection with the UE, supporting DC C-plane.
- Establish a dual-bearer connection with the S-GW.
- Being able to perform a bearer split within the MeNB.
- Being able to perform at least LTE/Wi-Fi interworking via ANDSF.

9.7 Transport

9.7.1 Background to Software Defined Network (SDN)

Software defined networks are a method for operators to reduce costs and make services more agile. Traditional networks based around the IP protocol have become ossified [25] and software defined networks evolved initially based around Openflow in campus networks break the proprietary functions embedded in routers/switches between the control plane and the data plane. Openflow enables a switch to be programmed with a set of rules determining where a packet goes based on the contents of the packet header. Decision can be based on a range of functions including MAC address, VLAN tag, IP source/destination address, DiffServ code point, UDP/TCP ports and other parameters. This approach deconstructs the traditional IP router or Ethernet switch usually embedded in proprietary electronics into potentially open platform heralding a massive inflection point in the business of networking equipment vendors. OpenFlow and SDN have been delayed in data center based network such as Google since 2012 [26].

At the same time leading network operators [27] such as AT&T, BT and others, identified network function virtualization as a way of “leveraging standard IT virtualisation technology to consolidate many network equipment types onto industry standard high volume servers, switches and storage, which could be located in Datacenters, Network Nodes and in the end user premises”. These two effects, networks which can be programmed by software and network functions which can be virtualised (NFV) are causing a revolution in networking technology because of expected cost savings and more flexible service delivery. SDN and NFV are an imperative for many network operators although the benefits in most cases are some way from realisation. The key standards body for NFV orchestration and management is the ETSI MANO [27] approach. The key standards body for SDN is the Open Networking Forum [28].

There are a number of SDN tools available. Firstly there is the OpenVswitch [29] openflow switch. This is easily instable in a Linux box. There are a range of white box switches in the market [30] based on the Trident-2 Broadcom [31] chip and similar. There are a range of openflow controllers. There is the NOX and its derivate POX [32]. Then there is the floodlight controller [33] which is linked to the big switch [34] initiative. OpenDaylight is a multi vendor initiative to support the OpenDaylight controller. This grouping seems to be a vendor defensive strategy from some of the large incumbent network equipment vendors. Onos is the



‘new kid on the block’ as of 2016 and is an initiative which seems to be driven from a network operator perspective.

9.7.2 SDN in the Triangle Testing Framework

The Triangle Testing Framework will have a Transport network component based on SDN network to better approximate a production network as this is the expected trend of 5G networks. An Openflow based SDN network will be used with the following elements:

- ONOS controllers
- Open vSwitch software switches
- Mininet based software switches for extended network simulation

ONOS controller has been selected as the current leading edge Openflow controller with significant vendor and operator support.

9.7.3 Overview of Motivation for Network Prioritization

RedZinc’s software defined network platform VELOX is a multi-domain orchestrator which offers applications a priority on the network. VELOX offers an API – Application Programming Interface for third party applications to invoke priority bandwidth on the network.

TRIANGLE proposes a differentiated Internet based on virtual path slicing. Internet core and access capacity is continuing to grow. Optic fibre is getting nearer to the home and the possibility of 5G with 1000x capacity beyond today’s capacity is on the horizon.

With high traffic asymmetric due to content sources (e.g. Netflix, Akamai, YouTube), content owners, who obtain advertising and subscription revenue from this content, can inject traffic into the originating autonomous system and expect it to be carried in the first mile access network without the first mile owner participating economically for conveying that traffic.

Application providers would like deliver new applications which require more and more bandwidth, especially video applications. Take for example video advertisements, which need to be instantaneous and are sensitive to buffering. It might be interesting for application providers to be able to open a guaranteed pipe to users to push advertising, or deliver, for example a 4K medical diagnostic tool.

Differentiation is one possible solution to support this. All bits on the public internet are treated equally today and there is little performance or economic differentiation and no correlation with value. Network infrastructure used to deliver voice and private enterprise networks use differentiation and prioritisation based on MPLS EXP¹⁶ bits or Diffserv Code Points¹⁷. The lack of differentiation on the public internet has caused significant business challenges for operators. For 5G there is an initiative [35] address differentiation in the regulation for 5G.

Virtual Path Slicing is a channel to market for QoS and allows service providers to deliver open 5G broadband with per event differentiation. 5G Service providers can empower applications owner to access QoS resources on the network. The resources are packaged into QoS events, made available to the application provider via an API- application programming interface and charged to the application provider on an itemised wholesale bulk basis.

¹⁶ Three experimental bits within multi-protocol label switching which are used for traffic classification with up to eight traffic classes.

¹⁷ Differentiated Services Classification offering Expedited Forwarding, Assured Forwarding or Best Effort.

We anticipate personalised flows in the future Internet gives an enhanced tier which creates a “win win win” - for the user, the application owner and the 5G telecommunications operator.

A high level view of the operational model is shown in Figure 4. The essential idea is to segment the network capacity (e.g. on a 50:50 basis) into a best effort domain and an 5-Net domain (anticipating 5G to come). This can be implemented by using an aggregated queue in a gateway network element dimensioned for 50% of the capacity for traffic painted as BE - best effort - using diffserv code points. The other 50% in the openflow domain can be painted EF or AF – expedited forwarding or assured forwarding - using diffserv code points. This OF domain can be sliced in a flow core and connection admission control techniques can be used to give a guarantee to the traffic. This is especially important for inelastic traffic such as live video which is sensitive to TCP back-off common in well loaded best effort networks. Application providers (Appcos) with multiple applications in the area of Internet of Things (IoT) eHealth, Consumer, Cloud, Media Social can use the slicing mechanism to obtain a slice of bandwidth across multiple autonomous systems and to the consumer connected via optic fiber access or 4G/5G radio access network. Of course, in exchange for obtaining guaranteed bandwidth to the user the applications provider who will be able to drive new business models (e.g. 4K webTV) can expect to receive a charge for conveying the guaranteed traffic. This can be implemented using cascade charging on a wholesale basis, from access to core to applications provider.

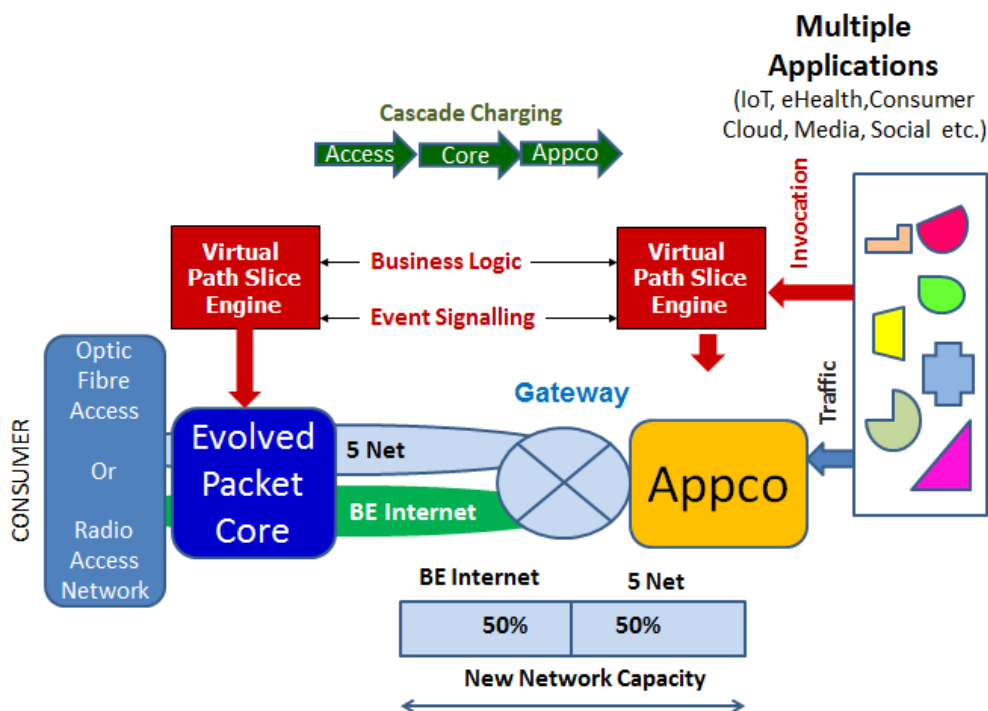


Figure 4 - Differentiated Service Model for 5G

9.7.4 Multi-domain orchestrator - VELOX VPS Engine

The Triangle Testing Framework will provide to applications realtime access to QoS differentiated services via the use of RedZinc’s multi-domain orchestrator VELOX with support for:

- Realtime invocation via JSON/TCP base API (documentation provided)



- RAN/EPC traffic differentiation
- SDN/Openflow traffic differentiation
- Single and Multi-administrative domain services
- Charging and cascade charging

Management of network configurations in VELOX is done via a web GUI with access to be defined as relevant to experiment roles.

9.7.5 Network Impairments

Triangle Testing Framework shall have the ability to emulate the following network impairments in the incoming and outgoing flows of the data and control plane.

- Latency
- Jitter
- Packet loss
- Packet re-ordering
- Bandwidth throttling

9.8 Web Portal

- The Web Portal shall be available 24/7.
- The Web Portal shall be available via a public URL with restricted access.
- The Web Portal shall provide a public request form to request access.
- The Web Portal shall provide means to change user preferences such a password.
- The Web Portal shall provide a password recovery mechanism.
- The Web Portal shall provide means to book the Testing Framework for carrying out tests.
- The Web Portal shall provide means to create new tests ahead of the actual execution.
- The Web Portal shall allow users to run tests during their booked period.
- The Web Portal shall provide feedback on the test execution.
- The Web Portal shall show results when a test completes its execution.
- The Web Portal shall allow tests to be executed and completed without user intervention once the test has been started.
- The Web Portal shall show a list of past experiments, including the configuration and results.
- The Web Portal shall allow the users to create new tests starting with an existing configuration.
- The Web Portal shall provide contextual help to users, depending on the current page or task.
- The Web Portal shall provide means for users to seek additional help outside the predefined help topics.



- The Web Portal shall provide means to list and/or track submitted apps or devices.

9.9 Geo-Location Capabilities

Adding location awareness to the app offers users a contextual experience. Nowadays, AR and Navigation apps require location awareness to function. Near future 5G apps will surely demand this feature as well.

Adding the ability of setting the environment for testing location-aware apps in the Triangle Testing Framework will be decided in the milestone MS10 (second version of the testing framework, month 15).



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11 Appendix 1: Use Cases of the Triangle testing framework

The Triangle Testing Framework use cases contain the following information:

- Description: A brief sentence that states what the user wants to be able.
- Actors: The type of user who interacts with the system to accomplish the task.
- Trigger: The event that starts the use case.
- Preconditions: Any states that the system must be in or conditions that must be met before the Use Case is started.
- Postconditions: Any states that the system must be in or conditions that must be met after the Use Case is completed successfully.
- Flow of Activities: The most common path of interactions between the user and the system.
- Alternate Course: Alternate path through the system and exception handling by the system.

11.1 Common

The following use case applies to all user profiles.

11.1.1 Application for Admission

Description

The user must apply to be admitted as a Triangle Testing Framework user.

Actors

Candidate User (any profile) and System Operator.

Preconditions

Not applicable.

Postconditions:

The user receives (or is denied) access to the Triangle Testing Framework.

Flow of Activities

1. The Candidate User accesses the system portal without logging in.
2. The Candidate User fills out an application requesting access to the system.
3. The Candidate User receives confirmation that the form was correctly sent to the system operator.
4. The System Operator reviews and accepts the application.
5. The System Operator delivers the necessary login credentials to the User.
6. The User receives the login credentials.

Alternate Courses

4. The System Operator reviews and rejects the application.



11.1.2 Booking the Testing Framework

Description

The User must book the system to use it.

Actors

User (any profile) and System Operator.

Preconditions

The User has been admitted.

Postconditions

The User is assigned a slot for running tests in the Testing Framework.

Flow of Activities

1. The User logs in into the system portal.
2. The User checks the currently available timeslots.
3. The User selects an available time slot.
4. The System Operator validates the availability of the system and the information provided by the User.
5. The User receives confirmation that the time slot was booked.

Alternate Courses

The System Operator rejects the reservation.

11.1.3 Configuring a test from an existing one

Description

The User can configure a new test starting from the configuration of an existing one.

Actors

User.

Preconditions

The User has been granted a slot for running tests. There is at least one previously configured test.

Postconditions

The new test is ready to be executed.

Flow of Activities

1. The User logs in to the system portal.
2. The User selects an existing test, already configured.
3. The User changes any of the existing parameters.

Alternate Courses

Not Applicable.



11.1.4 Conducting a test

Description

The User executes a configured test.

Actors

User.

Preconditions

The User has been granted a slot for running tests. The slot is currently active. There is at least one previously configured test.

Postconditions

The experiment test has been executed.

Flow of Activities

1. The User logs in to the system portal.
2. The User selects an existing test, already configured.
3. The User initiates the test.
4. The User receives limited live information while the test is in progress.

Alternate Courses

Errors during the execution of the test are shown to the user.

11.2 App Developer

11.2.1 Configuring a new Certification test

Description

The App Developer must provide the necessary information to execute the tests for a new App.

Actors

User (App Developer).

Preconditions

The User has been granted a slot for running tests.

Postconditions

The new test is ready to be executed.

Flow of Activities

1. The User logs in to the system portal.
2. The User selects the App under test.
3. The User selects the type of test: Certification
4. The User selects the type of application: Social Media, Game, Video Streaming, Navigation, or Other.



5. The system portal shows the list of Functional and Extra-Functional Properties that will be tested.
6. For each Property the User shall indicate the execution flow: How the Property can be measured in the App under test.

Alternate Courses

1. The App Developer uploads a new App or a new version of an existing App.

11.2.2 Configuring a new Experiment test

Description

The App Developer must provide the necessary information to execute the tests for a new App.

Actors

User (App Developer).

Preconditions

The User has been granted a slot for running tests.

Postconditions

The new test is ready to be executed.

Flow of Activities

1. The User logs in to the system portal.
2. The User selects the App under test.
3. The User selects the type of test: Experiment
4. The User selects the type of application: Social Media, Game, Video Streaming, Navigation, or Other.
5. The User selects the list of Functional and Extra-Functional Properties to be measured in the experiment.
6. For each Property the User shall indicate the execution flow: How the Property can be measured in the App under test. See example in Annex 1.
7. The User selects the list of 5G scenarios to be measured in the experiment (see section.
8. The User selects the list of 5G devices where the App will be tested.

Alternate Courses

1. The App Developer uploads a new App or a new version of an existing App.
2. The App Developer provides the additional information for an Experiment test: Assertions/other conditions to check

11.2.3 Analyzing the test results

Description

The App Developer analyses the available results after a test has been executed.

Actors

User (App Developer).



Preconditions

The App Developer has conducted a certification or experiment test.

Postconditions

Not Applicable.

Flow of Activities

1. The User logs in to the system portal.
2. The User selects an already executed test.
3. The User reviews the available information related to the test execution, which depending on the type of test and the outcome can be any of:
 - a. Triangle Mark
 - b. Network performance reports
 - c. App execution flow reports
 - d. Error traces
 - e. Full logs from the different test components.

Alternate Courses

Not Applicable.

11.3 Device Maker

11.3.1 Configuring a new Certification test

Description

The Device Maker must provide the necessary information to execute the tests for a new device.

Actors

User (Device Maker).

Preconditions

The Device Maker has been granted a slot for running tests. The Device has been sent to the Testing Framework.

Postconditions

The new test is ready to be executed.

Flow of Activities

1. The User logs in to the system portal.
2. The User selects the device under test.
3. The User selects the type of test: Certification.
4. The system portal shows the list of Functional and Extra-Functional Properties that will be tested.

Alternate Courses



Not Applicable.

11.3.2 Configuring a new Experiment test

Description

The Device Maker must provide the necessary information to execute the tests for a new device.

Actors

User (Device Maker).

Preconditions

The Device Maker has been granted a slot for running tests. The Device has been sent to the Testing Framework.

Postconditions

The new test is ready to be executed.

Flow of Activities

1. The User logs in to the system portal.
2. The User selects the device under test.
3. The User selects the type of test: Experiment.
4. The User selects the list of Key Performance Indicators to be measured in the experiment.
5. The User selects the list of 5G scenarios to be measured in the experiment (see section.
6. The User selects the list of Reference Applications which will be tested (see section.

Alternate Courses

Not Applicable.

11.3.3 Analyzing the test results

This use case is equivalent to 11.2.3, but with a device maker, a device test, and a potentially different set of results.

11.4 Researcher, Network and Service Operators

The use cases for App Developer and Device Maker use cases apply to these user profiles.

All the parameters available in the system are exposed to the user. A complete form with all parameter is made available; users can edit the values.



12 Appendix 2: Preliminary analysis of IoT Operating Systems

Specialized IoT OS's are designed for constrained devices (because they usually rely on batteries) in terms of processing, storage and power consumption.

Table 19 compiles the specialized IoT OS's with relevant participation in the industry [18]. The latest release is noted to reflect the activity of their respective development community.

Table 19 - Specialized IoT OS's

| Name | Latest Release | Technologies Supported |
|--------------------|-----------------------|--|
| <i>TinyOS</i> | August, 2012 | Broadcast based Routing, Probabilistic routing, Multi-path routing, Geographical Routing, Reliability based Routing, TDMA based Routing, Directed Diffusion, TinySec |
| <i>Contiki</i> | August, 2015 | 6LoWPAN, RPL, CoAP, TLS, DTLS |
| <i>Mantis</i> | April, 2013 | Wireless micro sensor platforms |
| <i>Nano-RK</i> | February, 2008 | RTLink, PCF TDMA, b-mac, U-Connect, WiDom |
| <i>LiteOS</i> | May, 2014 | JTAG |
| <i>FreeRTOS</i> | May, 2016 | TCP, UDP, Ethernet, TLS |
| <i>mbed OS</i> | March, 2016 | 6LoWPAN, CoAP, BLE, Wi-Fi, Zigbee IP, Zigbee LAN, Cellular, Ethernet, TLS, DTLS |
| <i>RIOT</i> | April, 2016 | 6LoWPAN, RPL, UDP, TCP, CBOR, CCN-Line, Open WSN, UBJSON |
| <i>Windows IoT</i> | October, 2015 | TCP, UDP, Ethernet, Wi-Fi |
| <i>Brillo</i> | February, 2016 | Weave, BLE, Wi-Fi |

According to [36], three IoT OS categories exist: multi-threaded, event-driven and worst-case real-time. It is believed that RIOT (multithreaded) [37], Contiki (event-driven) [38], and FreeRTOS (worst-case real-time) [39] will become dominant in the field of IoT in each category. However, large companies like Google, Huawei, Microsoft and ARM are developing their own IoT OS's, respectively Brillo OS [40], LiteOS [41], Windows IoT [42] and mbed [43]. Most surely they will also have an impact on the market share.



13 Appendix 3: eNodeB Capabilities

This section contains the list of requirements for the eNodeB providing cellular connectivity to the devices under tests (DUTs).

Cell Identities Parameterization

The system shall be able to modify the following parameters:

- Global Cell Identity
- Physical Cell Identity
- International Mobile Subscriber Identity (IMSI). At least 3GPP SIM cards.
- User Defined IMSI
- Mobile Country Code (MCC)
- Mobile Network Code (MNC)
- Tracking Area Code (TAC)
- Location Area Code (LAC)

Carrier Assignment

- The system shall support multiple carrier aggregation configurations.
- The system shall support a minimum of 4 active cells.
- The system shall support a minimum of 1 NB-IoT cell, either in stand-alone, in-band and guard band.

Carrier Setup

- The system shall allow the user to define the associated primary cell carrier (PCC) to the secondary cells carriers (SCC).
- The system shall allow the user to define the scheduling carriers of the NB-IoT and the SCC.
- The system shall support downlink aggregation type. Uplink aggregation support is optional.

Downlink Cell Power

- The system shall allow the user to define the power level of the DL transmission of a single resource element (15 kHz bandwidth).
- The system shall allow the user to define the power level of the DL transmission across the whole bandwidth assuming all resource elements are transmitting.

UE Power Control Mode

- The system shall provide an automatic UE power control mode which defines the target PUCCH and PUSCH.
- The system shall provide the means to allow for manual UE power control both in the downlink and in the uplink. The UE power is not adjusted unless the user explicitly sends a manual system of power to either the PUSCH or PUCCH.



- The eNB shall provide a power control mode where the UE is continuously sent DCI 0 messages, which include TPC bits telling the UE to increase the power level of the PUSCH by 1 dB. This also results in the PUSCH being continuously transmitted.
- The system shall provide a power control mode where the UE is told to increase or decrease its power level to reach the target power levels specified.

Power Boosting

- The system shall provide power boosting on the cell-specific reference signals (RS).
- The system shall provide support for PDSCH PA.
- The system shall provide support for PDSCH PB.
- The system shall provide support for PSS PA.
- The system shall provide support for SSS PA.
- The system shall provide support for other channels PA, such as PBCH, PCFICH, PHICH and PDCCH. Although these channels might be addressed all at the same time and not individually.

General Physical Layer Parameters: PHICH / PRACH

- The system shall support both normal and extended PHICH duration.
- The system shall support all PRACH configuration index.
- The system shall support defining a frequency offset for the PRACH as defined in TS 36.211.
- The system shall support the usage of different PHICH N_g values. These values are $N_g = \{1/6, 1/2, 1, 2\}$
- The system shall support defining the root sequence index for positive integers between 0 and 837, both inclusive, for preamble formats 0 to 3. In case preamble format 4 is selected (available only for TDD operation), allowed values are positive integers between 0 and 137, both inclusive.
- The system shall allow defining the size of the zero correlation zone of the random access preamble.

General Physical Layer Parameters: Control Region Configuration

- The system shall support configuring the numbers of symbols that are used for the control region. Supported values are 1, 2 and 3. The pre-set value for 1.4, 3, 5 MHz systems is CFI = 3. The pre-set value for 10, 15, 20 MHz is CFI = 2.
- The system shall support configuring the aggregation level (UE specific). The supported values are 1, 2, 4 and 8. The pre-set value is 2.
- The system shall support configuring the aggregation level (Common). The supported values are 4 and 8. The pre-set value is 4.

General Physical Layer Parameters: Reference Signal Hopping Configuration

- The system shall support configuring whether the group hopping pattern or sequence-shift hopping pattern is used to derive the sequence-group number. The valid options are: off, group or sequence.



- The system shall support configuring the cycle shift used for transmission of PUCCH when format 1, 1a or 1b is used. The valid options are ds1, ds2 and ds3.
- The system shall support configuring the sequence cyclic shift. The range of supported values is from 0 to 7. The pre-set value is 1.
- The system shall support configuring the PUSCH Hopping Offset.
- The system shall support configuring the nRB-CQI parameter.
- The system shall support configuring the nCS-AN. The range of supported values are from 0 to 7.

General Physical Layer Parameters: PCCH

- The system shall support configuring the Default Paging Cycle. The valid options are 32, 64, 128, 256 radio frames.
- The system shall support defining the NB, which sets how often the UE can be paged. The valid options are 1/32T, 1/16T, 1/8T, 1/4T, 1/2T, 1T, 2T, 4T. The pre-set value is 1T.

General Physical Layer Parameters: PUCCH

- The system shall support configuring the PUCCH Formats. The minimum supported options are Format 1b (with CS) and Format 3.

Physical Layer Parameters: CSI Reference Signal

- The system shall allow the user deciding if the CSI-RS are to be transmitted on the port specified by the CSI-RS Antenna Ports setting in CSI-RS Antenna Ports (or not).
- The system shall support configuring the CSI-RS Antenna Ports. The minimum valid options are 1 (Port 15), 2 (Ports 15, 16), 4 (Ports 15-18), 8 (Ports 15-22).
- The system shall support configuring the CSI-RS Subframe Configuration. The minimum range supported is from 0 to 154.
- The system shall support configuring the CSI-RS Resource Configuration. The minimum range supported is from 0 to 19 for FDD systems and 0 to 31 for TDD systems.

Physical Layer Parameters: Zero Power Configuration

- The system shall allow the user deciding if the CSI Zero Tx Power is used.
- The system shall support configuring the Zero Power CSI-RS Resource Configuration. The valid range is from 0 to 0xFFFF (Hexadecimal).
- The system shall support configuring the Zero Power CSI-RS Subframe Configuration, which allows the user to define the user how frequently the Zero Power CSI-RS occurs. The supported values are in the range from 0 to 154.

Downlink Scheduling

- The system shall support selecting the downlink antenna configuration (DL Antenna Config). The minimum supported options are D1U1, D1U2, D2U2, D4U2, D4U4, D1U4, D2U4, D8U2, D8U4. (DxUy, where x is Number of DL Tx antennas on The UXM; y is Number of DL Rx antennas on the UE).
- The system shall support selecting the Transmission Mode (TM) for PDSCH transmission. The possible values for this parameter depend on the currently selected



antenna configuration. Transmission modes 1, 2, 3, 4, 7 (SISO), 7 (MIMO), 8 and 9 shall be supported.

- The system shall support selecting the DL Resource Allocation Type. The minimum supported options shall be Type 0 and Type 2 Localized.
- The system shall support indicating the number of codewords to a UE during a subframe when the transmissions mode selected allows spatial multiplexing. The minimum supported values are one or two codewords.
- The system shall support selecting the number of layers to map a single codeword or two codewords when DL Antenna Configuration is set to D4U4.
- The system shall support using 256 QAM in the downlink.
- The system shall support CQI to MCS Mapping to determine if the eNodeB should use the user-specific DL IMCS, or should determine the MCS based on the received CQI reports from the UE.
- The system shall allow configuring the MCS used in each subframe for the 1st codeword and the 2nd codeword (if available).
- The system shall allow to define the resource block groups of each subframe are allocated to the UE.
- The aforementioned configuration parameters could be different for each primary cell.

Downlink Scheduling – Auto Mode

- The system shall allow the user to define the number of resources blocks that are assigned to the UE.
- The system shall allow the user choose to constrain the MCS index that is used on the DL by either constraining the MCS index value, or specifying the maximum downlink modulation that can be used.
- The system shall allow the user select the maximum downlink MCS (if applies).
- The system shall allow the user select the maximum modulation.
- The aforementioned configuration parameters could be different for each primary cell.

Uplink Scheduling

- The system shall support using 64 QAM in the uplink.
- The system shall support defining the MCS in each subframe.
- The system shall support defining which subframes are allocated in the uplink.
- The system shall support aperiodic CQI reports for each uplink subframe.

Scheduling - Codebook

- The system shall allow the user to control the UE reporting related to PMI and RI reports via the Codebook Subset Restriction.
- The system shall support configuring an Alternative Codebook when Transmission mode 9 with 4 CSI-RS port configured; when this codebook is in use, PMI feedback from the UE will reference the tables 3GPP TS 36.213 s7.2.4 [44] rather than the tables in 3GPP TS 36.211 [45].



Scheduling – Enhanced Inter-cell Interference Coordination (eICIC)

- The system shall allow configuring a cell as Aggressor, Victim or simply turn eICIC off. The pre-set value is off.
- The system shall allow the user deciding when the cell will start to apply the configurations associated with its ABS pattern (if an aggressor) or its aggressor ABS pattern (if a victim). The possible values are immediately or after UE attaches.

Scheduling – eICIC – Aggressor Configuration

- The system shall allow defining the ABS Pattern Type. This parameter is dependent on the Duplex Mode and, if TDD is being used, the uplink/downlink configuration. The range of supported values are listed in the table below:

Table 20 - ABS Pattern Type supported by the Triangle Testing Framework

| | |
|-----------------|------------------------|
| 36.521–1 FDD 1, | 36.521–1 TDD 1, |
| 36.521–1 FDD 2, | 36.521–1 TDD 2, |
| 36.521–1 FDD 3, | 36.521–1 TDD 3, |
| 36.521–1 FDD 4, | Custom 40 Bit Pattern, |
| 36.521–1 FDD 5, | Custom 20 Bit Pattern, |
| 36.521–1 FDD 6, | Custom 70 Bit Pattern, |
| 36.521–1 FDD 7, | Custom 60 Bit Pattern |

- The system shall support defining custom FDD ABS 40 bit pattern. The range of supported values is from “0” to “FFFFFFFF”.

Scheduling – eICIC – Aggressor Boosting

- The system shall allow defining the behaviour of the PBCH channel during Aggressor ABS. The possible values are Default, Disabled During ABS, Reduced During ABS.
- The system shall allow defining the behaviour of the PSS channel during Aggressor ABS. The possible values are Default, Disabled During ABS, Reduced During ABS.
- The system shall allow defining the behaviour of the SSS channel during Aggressor ABS. The possible values are Default, Disabled During ABS, Reduced During ABS.
- The system shall allow defining the behaviour of the PCFICH channel during Aggressor ABS. The possible values are Default, Disabled During ABS, Reduced During ABS.
- The system shall allow defining the behaviour of the PHICH channel during Aggressor ABS. The possible values are Default, Disabled During ABS, Reduced During ABS.
- The system shall allow defining the behaviour of the PDCCH channel during Aggressor ABS. The possible values are Default, Disabled During ABS, Reduced During ABS.
- The system shall allow defining the behaviour of the PDSCH channel during Aggressor ABS. The possible values are Default, Disabled During ABS, Reduced During ABS.
- The system shall allow defining the behaviour of the OCNG channel during Aggressor ABS. The possible values are Default, Disabled During ABS, Reduced During ABS.



Scheduling – eICIC – Victim Configuration

- The system shall allow defining the Aggressor ABS Pattern Type. The possible values are listed in the table below:

Table 21 - Aggressor ABS Pattern Type supported by the Triangle Testing Framework

| | |
|-----------------|------------------------|
| 36.521–1 FDD 1, | 36.521–1 TDD 1, |
| 36.521–1 FDD 2, | 36.521–1 TDD 2, |
| 36.521–1 FDD 3, | 36.521–1 TDD 3, |
| 36.521–1 FDD 4, | Custom 40 Bit Pattern, |
| 36.521–1 FDD 5, | Custom 20 Bit Pattern, |
| 36.521–1 FDD 6, | Custom 70 Bit Pattern, |
| 36.521–1 FDD 7, | Custom 60 Bit Pattern |

- The system shall support defining custom FDD ABS 40 bit pattern. The range of supported values is from “0” to “FFFFFFFF”.
- The system shall support defining RLM/RRM Measurement Subframe Pattern Type. The possible options are listed in the table below:

Table 22 - RLM/RRM Measurement Subframe Pattern supported by TRIANGLE

| | |
|--------------------------------|--------------------------------|
| 36.521–1 FDD 1, | Custom RLM/RRM 40 Bit Pattern, |
| 36.521–1 FDD 2, | Custom RLM/RRM 20 Bit Pattern, |
| 36.521–1 FDD 3, | Custom RLM/RRM 70 Bit Pattern, |
| 36.521–1 TDD 1, | Custom RLM/RRM 60 Bit Pattern |
| Custom RLM/RRM 40 Bit Pattern, | |

- The system shall allow activating or deactivating CSI Subframe Pattern Configuration.
- The system shall allow defining CSI Subframe Set 1 Pattern. The possible values are as Aggressor ABS, Custom CSI Subframe Set 1 20 Bit Pattern, Custom CSI Subframe Set 1 40 Bit Pattern, Custom CSI Subframe Set 1 60 Bit Pattern, Custom CSI Subframe Set 1 70 Bit Pattern.
- The system shall allow sending neighbour CRS info to the UE, which allows the UE to know about the cell specific reference signals used by the cells if using the same frequency. The possible options are enabled or disabled. These parameters only apply to victim cells.
- The system shall allow configuring dedicated downlink allocations. The possible options are Enabled, Disabled During Aggressor’s ABS, Disabled During Aggressor’s Non ABS.
- The system shall allow configuring dedicated uplink allocations. The possible options are Enabled, Disabled During Aggressor’s ABS, Disabled During Aggressor’s Non ABS.



- The system shall allow configuring when transmissions of SIBs other than SIB1 take place. The possible options are Enabled, Disabled During Aggressor's ABS, Disabled During Aggressor's Non ABS.
- The system shall allow configuring when transmissions of the PHICH take place. The possible options are Enabled, Disabled During Aggressor's ABS, Disabled During Aggressor's Non ABS.

MAC/RLC/PDCP Scheduling Request

- The system shall allow the user to decide whether the SchedulingRequestConfig IE is transmitted. The possible options are On or Off.
- The system shall allow defining the Scheduling Request PUCCH Resource Index. The valid range is from 0 to 2047, while it should be noted that the correct values will depend on the uplink bandwidth restrictions and the cyclic prefix used.
- The system shall allow controlling the maximum number of SR transmissions that the UE is allowed to perform before switching to a random access procedure, in case it does not receive any response to the requests. The possible options are 4, 8, 16, 32 and 64.
- The system shall allow controlling on which uplink subframe the UE shall transmit the scheduling request. The valid range of values is from 0 to 155.

MAC/RLC/PDCP RACH Parameters

- The system shall allow configuring the C-RNTI value that is used for scrambling the data sent/received from the UE. The valid range of values is from 0x0001 to 0xFFFF3.
- The system shall allow configuring the number of Random Access Preambles. The valid range of values is from 4 to 64 by step of 4.
- The system shall allow specifying the power ramping step in dB that the UE should apply when transmitting successive random access preambles. The possible options are 0 dB, 2 dB, 4 dB, and 6 dB.
- The system shall allow controlling the duration of the random access response window in subframes. The possible options are 2, 3, 4, 5, 6, 7, 8, 9 and 10.
- The system shall allow specifying the Preamble Initial Received Target Power by the UE during the random access procedure, without considering preamble format based offset. The valid range of values is from -120 dBm to -90 dBm by step of 2 dB.
- The system shall allow specifying the Maximum Number of Preamble Transmissions that the UE should attempt during the random access procedure in case it does not receive response from the network.
- The system shall allow controlling the Contention Resolution Timer which is used in the random access procedure after the transmission of Msg 3 (RRC Connection Request). The valid range of values is from 8 to 64 by step of 8 subframes.

MAC/RLC/PDCP HARQ Parameters

- The system shall allow controlling the number of times the LTE application attempts to transmit a downlink transport block before it is discarded. This is done in the Downlink Max HARQ Transmissions parameter. The valid range of values is from 1 to 8, in addition to 10, 12, 16, 20, 24 and 28.
- The system shall support handling HARQ feedback type "ANY" as either NACK or ACK.



- The system shall allow configuring the retransmissions allocation mode. The possible values are Adjust MCS or Same MCS.
- The system shall allow configuring the TDD feedback mode. The possible values are Bundling and Multiplexing.
- The system shall allow configuring the maximum number of uplink HARQ transmission that determines the number of times the eNodeB expects the UE to attempt to transmit a transport block before it is discarded. Setting this value to 1 effectively disables UL HARQ operation, since it prevents UL retransmissions. The valid range of values is from 1 to 8.
- The system shall allow defining the downlink redundancy version sequence that controls the redundancy version used if a transport block is retransmitted. The valid range is a list of up to 28 values <0 ... 3>. For any omitted values, 0 is used. The pre-set values is 0, 1, 2, 3, 0.
- The system shall allow configuring the Msg3 maximum HARQ transmissions. The valid range of values is from 1 to 8.

MAC/RLC/PDCP DRB Configuration

- The system shall allow configuring the settings that are common between Default and Dedicated bearers.
- The system shall allow selecting the RLC mode of operation used on the DRB. The valid options are AM (Acknowledged Mode) and UM (Unacknowledged mode).
- The system shall allow the user defining the DRB identity that is assigned to the UE during the RRC Connection Reconfiguration process. The valid range of values is from 1 to 32.
- The system shall allow configuring the length of the PDCP sequence number. The valid options are 7 or 12 bits.

MAC/RLC/PDCP DRB – UM Mode

- The system shall allow defining the RLC sequence number. The valid options are 5 or 10 bits.
- The system shall allow controlling how long the receiving RLC UM entity in the UE will wait, when receiving an RLC PDU that has its sequence number out of order before delivering the PDU to higher layers. The valid range is from 0 to 200 ms (in 5 ms increments up to 100 ms then in 10 ms increments up to 200 ms).

MAC/RLC/PDCP DRB – AM Mode

- The system shall allow controlling how long the receiving RLC AM entity in the UE waits when receiving RLC AM PDUs that are out of order before triggering a STATUS report. This is done in the T-Reordering parameter. The valid range is from 0 to 200 ms (in 5 ms increments up to 100 ms then in 10 ms increments up to 200 ms).
- The system shall allow controlling how long the UE's RLC AM entity waits for an ACK or NACK of an RLC AM PDU that it transmits. This is done in the T-Poll Retransmit parameter. The valid range is from 0 to 250 ms (in 5 ms step increments), 250 to 500 ms (in 50 ms step increments).
- The system shall allow controlling how many bytes of data are transmitted by a UE's RLC AM entity before it set the polling bit in the RLC data PDU that it transmit. The possible



values are 25 kB, 50 kB, 75 kB, 100 kB, 125 kB, 250 kB, 375 kB, 500 kB, 750 kB, 1000 kB, 1250 kB, 1500 kB, 2000 kB, 3000 kB, Infinity.

- The system shall allow limiting the frequency of STATUS report transmitted by the receiving RLC AM entity in a UE. This is done in the T-StatusProhibit timer parameter. The valid range is from 0 to 250 ms (in 5 ms step increments), 250 to 500 ms (in 50 ms step increments).
- The system shall allow controlling how many PDUs are transmitted by a UE's RLC AM entity before it sets the polling bit in the RLC data PDU that it transmit. This is done in the Poll PDU parameter. The valid options are p4, p8, p16, p32, p64, p128, p256, plnfinity.
- The system shall allow configuring how many times the RLC AM entity in the UE retransmit an RLC PDU. This is done in the Max Retx Threshold parameter. The possible options are t1, t2, t3, t4, t6, t8, t16, t32.

MAC/RLC/PDCP DRX Mode

- The system shall allow controlling whether the DRX-Config information element of the RRC Connection Reconfiguration message is to be set to setup or to release. This enables or disables Connected Mode DRX in the UE.
- The system shall support Long DRX Cycle.
- The system shall support specifying the long DRX cycle in number of subframes. This is done in the longDRXCycle parameter. The possible values are SF10, SF20, SF32, SF40, SF64, SF80, SF128, SF160, SF256, SF320, SF512, SF640, SF1024, SF1280, SF2048, SF2560. Some restrictions might apply when ShortDRX is active.
- The system shall support specifying the number of consecutive PDCCH subframes during which the UE is required to monitor PDCCH in PDCCH subframes in a DRX cycle. This is done in the OnDuration Timer parameter. The possible options are 1, 2, 3, 4, 5, 6, 8, 10, 20, 30, 40, 50, 60, 80, 100, 200 in number of PDCCH subframes.
- The system shall support specifying the number of consecutive PDCCH-subframe(s) for the UE to expect a DL retransmission after a HARQ RTT timer expires. This is done in the drx-RetransmissionTimer parameter. The possible values are 1, 2, 4, 6, 8, 16, 24, 33 in number of PDCCH subframes.
- The system shall support specifying the number of consecutive PDCCH subframe(s) after successfully decoding a PDCCH indicating an initial uplink or downlink user data transmission for this UE. This is done in the drx-InactivityTimer parameter. The possible values are 1, 2, 3, 4, 5, 6, 8, 10, 20, 30, 40, 50, 60, 80, 100, 200, 300, 500, 750, 1280, 1920, 2560 in number of PDCCH subframes.
- The system shall support battery saving for DRX. Furthermore the system shall provide different behaviors to adjust the battery drain that the UE experiences. The options are Disabled, Skip UL Grant for Pending UL Retx, Skip Also Inactivity Timer, Tx During On Duration Only.
- The system shall support configuring the DRX Start Offset. The range of possible values are from 0 to (longDRXCycle – 1).
- The system shall support Short DRX.



- The system shall support defining the short DRX cycle. This is done in the shortDRXCycle parameter. The possible values are 2, 5, 8, 10, 16, 20, 32, 40, 64, 80, 128, 160, 256, 320, 512, 640 in subframes.
- The system shall support specifying the time duration that the UE uses short DRX cycle before starting to use the long DRX cycle. The valid range of values is from 1 to 16, where for example a value of 3 corresponds to 3 * the number of subframes specified in the shortDRXCycle parameter.

RRC Timers

- The system shall allow defining the T300 timer.
- The system shall allow defining the T301 timer.
- The system shall allow defining the T310 timer.
- The system shall allow defining the T311 timer.
- The system shall allow defining the N310 parameter. The possible values are 1, 2, 3, 4, 6, 8, 10, 20.
- The system shall allow specifying the number of seconds that can pass without proof that a UE is present on the cell before the connection status is changed. The valid range is from 2 to 60 seconds.
- The system shall allow setting the number of seconds the UE remains in the RRC Connected state while not transferring any data on a DRB before the eNodeB sends an RRC Connection Release to it. The valid range is from 1 to 2000 seconds.

General NAS Parameters

- The system shall allow the user to choose between automatically responding to ESM messages and assigned the configuration that the UE is asking for or being able to explicitly define the response.
- The system shall allow setting the access point name (APN) to be used when using EPC Response State of Auto and when the UE does not specify an APN. This parameter is a string with a maximum of 100 characters.
- The system shall allow defining the EPS attach type. The valid options are "auto" where the attach type sent by the UE is used in the attach accept message; and "manual" where the attach type sent by the UXM are those defined in a scenario file.
- The system shall support IPv6.
- The system shall support IPv6 Router Advertisement (LTE).
- The system shall support IPv6 Router Advertisement (LAN).

EPC Bearer Configuration

- The system shall support configuring the EPS Bearer configuration.
- The system shall support configuring the IP Address of the UE for either IPv4 or IPv6.
- The system shall support subnet routing.
- The system shall support both DNS and P-CSCF.
- The system shall allow defining the T301 timer.



Measurement Configuration

- The system shall allow periodic CSI reporting.
- The system shall allow aperiodic CSI reporting.
- The system shall allow specifying the primary cell report interval.
- The system shall allow specifying the SRS configuration. The possible options are Deactivated, Activated in Cell but not for UE, Periodic SRS Activated.
- The system shall allow configuring the L3 Filter Coefficient (RSRP).
- The system shall allow configuring the L3 Filter Coefficient (RSRQ).
- The system shall allow support for measurement gaps.

Measurement Configuration – Periodic Reporting

- The system shall allow defining the CQI/PMI Feedback Type.
- The system shall allow defining the CQI/PMI Configuration Index corresponding to CSI subframe set 1.
- The system shall allow defining the RI Reporting Configuration Index to CSI subframe set 1.
- The system shall allow defining the CQI/PMI Configuration corresponding to CSI Subframe set 2 (if configured).
- The system shall allow defining the RI Reporting Configuration Index to CSI subframe set 2.
- The system shall allow specifying the cqi-PUCCH-ResourceIndex.

Basic Security Configuration

- The system shall allow defining the authentication key.
- The system shall allow selecting the NAS Security Algorithm.
- The system shall allow selecting the RRC Security Algorithm.
- The system shall allow configuring the AMF Value.
- The system shall allow configuring the Key Value.
- The system shall allow configure the OP Value.

Miscellaneous

- The system shall support CMAS / ETWS.
- The system shall support LTE intra-RAT and LTE inter-RAT mobility with W-CDMA, TD-SCDMA or GSM using two independent cells.
- The system shall support LTE protocol messaging system.
- The system shall provide support for SCPI.
- The system shall provide support for Wi-Fi Offloading



14 Appendix 4: Preliminary analysis of Android VR App testing

The goal of this appendix is to compile the results of a preliminary analysis on how to test smart phone based VR apps.

This analysis can be also applied to Android gaming apps and Android Augment Reality apps as the respective programming development kits are similar.

The following Android VR Apps have been analyzed for the elaboration of this report:

- CardBoard: 5+ million
- Google Street View: 500+ million downloads
- VR YouTube 3D Video: 1 million
- Fulldive VR: 1 million
- Jurassic VR-Google Cardboard: 1 million
- VR Roller Coaster: 1 million (discarded: It does not download any data)
- Planner 5D – Interior Design: 1 million (discarded: It does not download any data)
- VR Cinema for CardBoard: 1 million

Understanding VR apps

There are a wide variety of applications for virtual reality which include: Architecture, Sport, Medicine, The Arts and Entertainment.

The aim is for a natural, free-flowing form of interaction which will result in high demand of download bandwidth.

When VR is achieved by smart phones, the accelerometer and gyroscope give VR app a sense of motion and position, allowing users to tilt their head and even spin around completely to see more of the virtual world being drawn.

Nowadays the VR experience is fixed since users cannot get up and walk around to see more of the world around them. That does not mean the video itself cannot move - in fact there are many examples like roller coasters and space simulation relies heavily on making it feel like users are moving around¹, when in fact they you are not moving at all.

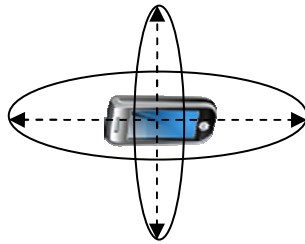
The evolution of VR apps will include positional tracking. Currently, leaning into a scene does nothing because smart phone VR based has no sense of where the head is in space, only how it is oriented rotational from the launch point. This *positional tracking* understand where a user's head is in relationship to the virtual environment. It is positional tracking the permits freedom of movement. The more sophisticated systems track the position of a participant's entire body. This is accomplished by using a combination of cameras on the headsets and cameras and other sensors in the environment. Some vendors include sensor stand that create configurable virtual rooms, complete with virtual walls that appear as grids within VR experiences as users approach them

Performing Motion

The accelerometer and gyroscope in the smart phone give the VR app a sense of motion and position, allowing users to tilt their head and even spin around completely to see more of the virtual world being drawn.

Impact on testing: Need to reproduce tilt and rotation in the device. Two options:

- Real: Mechanical setup to rotate on X and Y axis the device



- Emulation: Android SDK does not allow setting values to the gyroscope

Performing Movement

Nowadays the VR experience is fixed. Users cannot just get up and walk around to see more of the world around them.

In CardBoard app for example, users need to tap on the screen to move towards where they clicked. If the user clicks again, then the user stops walking.

Impact on testing:

- Real: Mechanical setup to perform touch screens
- Emulation: Android SDK allows implementing user interaction

Retrieving VR App State

Like gaming apps, the VR apps are programmed in an Android UI Canvas where the graphical engine works (e.g., Open GL). This canvas is generally used in all App views which require the GPU of the device: gaming Apps, VR apps, AR apps, etc. Therefore, the outcome of this analysis can be extrapolated to gaming and AR apps.

Impact on testing: Android Test Automation technologies (Selenium, Appium, etc.) cannot “see” the UI properties inside an App Canvas.

For example, CardBoard UI:



Figure 5 - CardBoard UI Screenshot

What Android Test Automation sees:

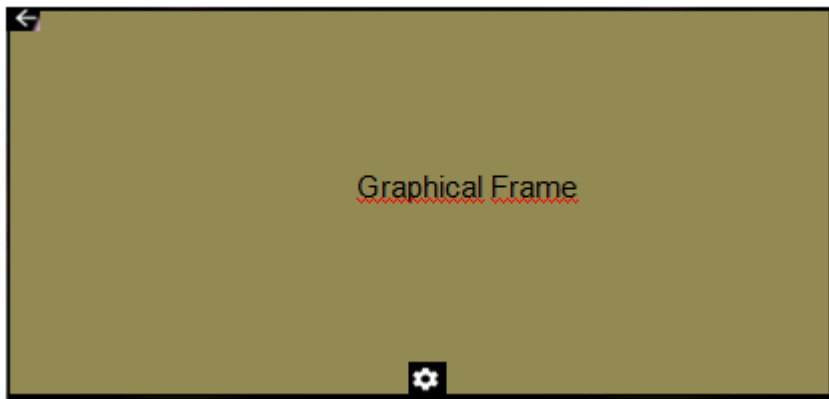




Figure 6 - CardBoard UI as seen by Android Automation Framework

Therefore, programmatically in the view above, Android Test Automation based technologies only allows to include in the script the following actions: click on , click on , or tap at any point in the frame (based on X-Y screen coordinates).

However, an script could not click on “Tour Guide” button because the programming framework would not see that button as it resides inside the Graphical frame.

Another consequence of VR Apps being embedded in an opaque frame cannot read any VR app state, which could be used to calculate specific KPI. For instance, in Netflix “spinner” UI element can be used to calculate the occurrences of re-buffering.

Moreover, starting the VR experience with Android Test Automation scripts is not even possible. For example, in CardBoard once users launch the App, they need to start the VR experience. This is done by physically aiming with the device at the desired button. As explained above, Android Test Automation cannot see those buttons, so that selection action cannot be automated by the Triangle Testing Framework.



Figure 7 - Starting VR experience in CardBoard

This mode of operation is common in all VR Apps which have been tested during the elaboration of this section.

Consequently, when the user of the Triangle Testing Framework is an App developer, they should provide means to automate some actions such as start VR experience and also expose the states of the App that eventually enables the testing framework computing the target KPIs.



Table 23 summarizes the outcome of the VR app testing preliminary analysis.

Table 23 - VR apps testing requirements

| Action | Impact on Testing |
|----------------------------|---|
| <i>Rotation</i> | Mechanical: X-Axis turning table |
| <i>Tilt</i> | Mechanical: Y-Axis turning table |
| <i>Movement</i> | Software: Android Test Automation |
| <i>Start VR Experience</i> | Software: App developer shall provide API |
| <i>Read VR App State</i> | Software: App developer shall provide API |