Deliverable D4.5
Testbed extension and operation plan

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European Commission

5G PPP

Executive summary

One of the major challenges of the 5G-ENSURE project was to provide a testbed environment allowing to evaluate and validate the efficiency of the 5G-ENSURE security enablers in order to address the security requirements of 5G Networks. The next coming challenge for this activity is to make it sustainable.

This deliverable provides a marketing analysis of 5G-ENSURE testbed including landscaping and positioning in order to work on the sustainability beyond the duration of 5G-ENSURE project. It also includes a testbed users' survey in order to list the lessons learned from the current status and usage of the testbed in the scope of 5G-ENSURE project. Finally, the document gives a view of what should be a 5G testbed architecture for the next phases of 5G research and innovation programs.

Our recommendation is to clearly express the 5G-ENSURE testbed value proposal: it should be a ready to use Pre-5G End-to-end integration (flexible, multi-tenant and neutral) environment, including various Radio Access Networks. B-COM is willing to build a service offer, named b<>com *Flexible Netlab*. This offer would be derived from 5G-ENSURE testbed, focusing on security with products' certification with ITSEF partnership.

Foreword

5G-ENSURE belongs to the first group of EU-funded projects which collaboratively develop 5G under the umbrella of the 5G Infrastructure Public Private Partnership (5G-PPP) in the Horizon 2020 Programme. The overall goal of 5G-ENSURE is to deliver strategic impact across technology and business enablement, standardisation and vision for a secure, resilient and viable 5G network. The project covers research & innovation - from technical solutions (5G security architecture and testbed with 5G security enablers) to market validation and stakeholders engagement - spanning various application domains.

This document aims to provide testbed competitive landscape and 5G-ENSURE positioning in this landscape, in order to share these views within the 5G-PPP ecosystem.

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Abbreviations

5G-PPP	5G Infrastructure Public Private Partnership
CESTI	Centre d'Evaluation de la Sécurité des Technologies de l'Information
FTE	Full-Time Equivalent
IT	Information Technology
ITSEF	Information Technology Security Evaluation Facility
IoT	Internet of Things
NFV	Network Functions Virtualization
NFVi	NFV Infrastructure
QoS	Quality of Service
SDN	Software Defined Networking
TRL	Technology Readiness Level
VNF	Virtualized Network Function

1 Introduction

1.1 Objectives

This document is the extension and operation plan for the security testbed setup in the scope of 5G-ENSURE project. This plan takes into account inputs from others tasks and WPs of the project, such as the lessons learned during the test sessions, the WP5 perspectives and the roadmap of future 5G networks security developments. Testbed sustainability shall be studied taking into account competitive landscape including other 5G-PPP awarded projects which may include a testbed in their scope but also any national or EU level initiative where a testbed is at stake. Any model including collaboration with the 5G-ENSURE testbed could represent an opportunity either from a technical and or funding perspective.

In this document, sustainability of the 5G-ENSURE testbed is looked at in the light of the released security enablers within the terms and conditions which apply to 5G-ENSURE partners. This has been explicitly addressed by Deliverable D4.2 with a dedicated annex named “5G-ENSURE Testbed Terms of Use”. Beyond the 5G-ENSURE project, this document should be enhanced to define how the testbed could be open to other 5G-PPP awarded project partners as well as any potential testbed customer.

Finally, this document aims to provide some materials for the project conclusion and the possible next steps for the security testbed. The scenario that is addressed by this document is the technical and commercial operation of a 5G security testbed by one of the current partners of 5G-ENSURE, i.e. b<>com which has branded its testbed as **b<>com * Flexible Netlab *.** As the 5G-ENSURE testbed has been designed as a meta-testbed with a design that is publicly available and with building blocks mainly based on open source solutions, any organization that would be interested to deploy a clone of 5G-ENSURE testbed can do it. A key differentiator could be the availability of a list of security enablers that could be instantiated on the testbed. So an action will be to check with 5G-ENSURE partners the type of license that can be granted for security enablers outside the scope of 5G-ENSURE and the consortium agreement.

1.2 Methodology

After a business model identification based on market surveys, a classical marketing plan will be used to propose some key points about service offer and business plan (Business Model canvas, refer [1]). It includes a competitive landscape analysis and lists the key points to build a sustainable testbed.

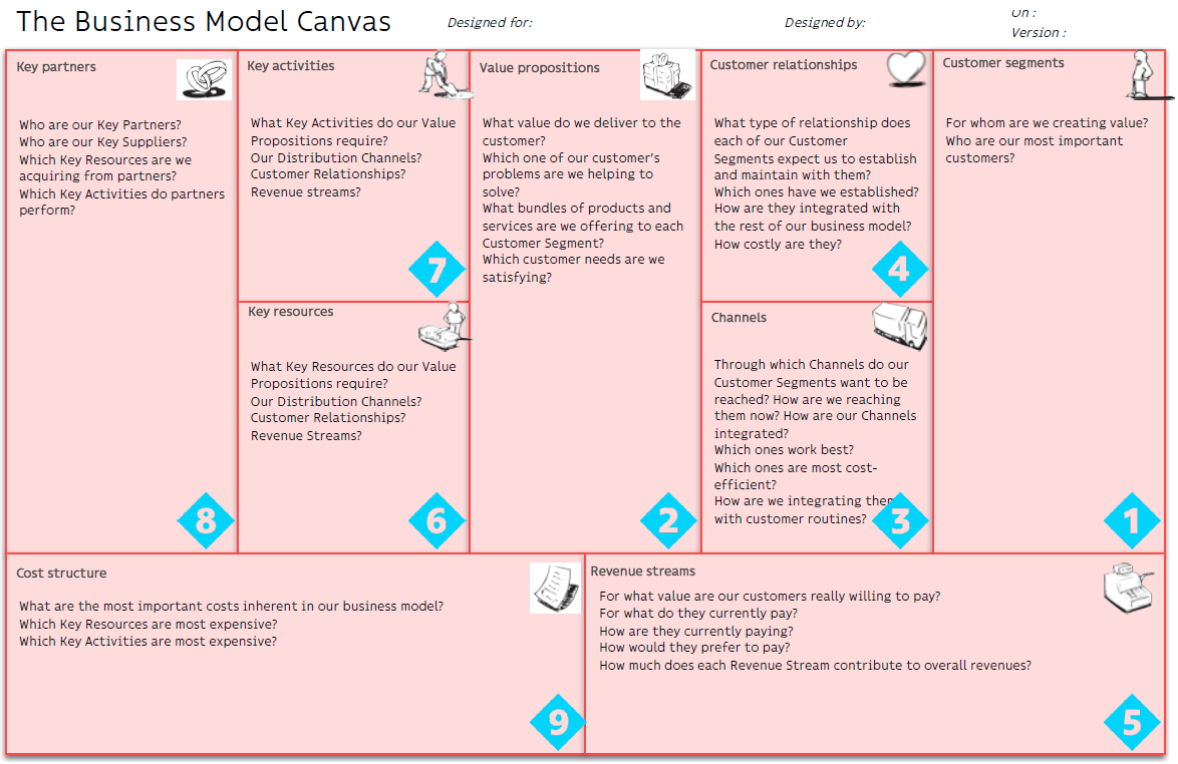

Figure 1: Business Model Canvas

1.3 Partners' roles

Role of Partners:

- b<>com has established a marketing strategic plan with the rules and business model (derived from its service offer), in order to make such a testbed sustainable. b<>com has deployed a pre-5G testbed services for its own use at French National level and is currently involved in three European projects that imply testbed activities: H2020 5G-ENSURE, H2020 5GinFire, H2020 One5G and also Celtic+ SENDATE. b<>com inherited also some background from a 4G testbed that was named ImaginLab and which was operated by Images & Réseaux cluster (b<>com has been spun off from this cluster) in the 2010-2013 periods.
- VTT contributed to the roadmap towards a more general 5G security testbed as part of a federated 5G network test environment.

2 Testbed definition

According to [2], a testbed is “a piece of equipment used for testing new machinery, especially aircraft engines.” For example: “fan blades were subjected to fatigue tests on laboratory test beds”. With a figurative definition, it is also used in other circumstances: “a test bed for new technology”, which applies for 5G-ENSURE.

Trying to define a testbed more precisely, it is composed of testbed nodes, each node being composed of a “set of hardware and software resources provided and operated by some Parties for the other Parties for the implementation of the Project”, as defined in [3]. In a 5G mood and DevOps approach, implementation is meant to provide for integration and deployment for testing and experimentation.

We can distinguish various types of testing or experimentation platform according to their target:

- Research, for development and TRL ≤4
- End-to-End Integration, to integrate enablers and VNFs with 4< TRL < 8 within state-of-the-art architecture
- Pre-commercial, for products with general or early access release and TRL ≥8

TRL #	Definition
TRL 9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
TRL 8	System complete and qualified
TRL 7	System prototype demonstration in operational environment
TRL 6	Technology demonstrated in relevant environment (industrial environment in the case of key enabling technologies)
TRL 5	Technology validated in relevant environment (industrial environment in the case of key enabling technologies)
TRL 4	Technology validated in lab
TRL 3	Experimental proof of concept
TRL 2	Technology concept formulated
TRL 1	Basic principles observed

Table 1: Technology Readiness Level definition

By testbed, 5G-ENSURE project means a testing environment for partners, providing the hardware and software resources including tools for Quality Assurance in order to evaluate enablers. The security enablers and the building blocks (Virtual Network Functions) are issued from research activities by partners and are required to have a TRL > 4 (so previously validated in a laboratory environment).

The 5G-ENSURE shall fulfil the requirements expressed by the “5G Manifesto for timely deployment of 5G in Europe” (refer to [4]):

- “*Before 2018 (before the availability of the first 5G 3GPP release): Technology trials run by independent trial consortia in various countries, independent of the status of standardisation, demonstrate and validate new 5G capabilities as well as foster an ecosystem around new 5G capabilities. Vertical industries will already be involved in this phase.*

- *Around 2018 (5G 3GPP first release close to being finalised – and additional frequency spectrum for 5G expected to be identified in WRC 2019 to enable the full performances capabilities of 5G in terms of capacity and speed): European stakeholders agree on trial specifications (use-cases, scenarios, interfaces, agreement to transfer use-cases across trial networks) valid for pan European trials, based as much as possible on standard-compliant systems. These trials aim to demonstrate wider interoperability and support for vertical use-cases in order to claim global public attention.*"

5G-ENSURE does not target pre-commercial experimentation or any activity similar to Living Lab experimentation, that may require a large Radio Access Network coverage and end-users' involvement in a 5G use case. Such pre-commercial experimentation environment shall rely on telecom infrastructure vendors and shall be operated by incumbent telecom operators. The figure hereunder gives a position of the 5G-ENSURE testbed in the Pan-European 5G trials roadmap.

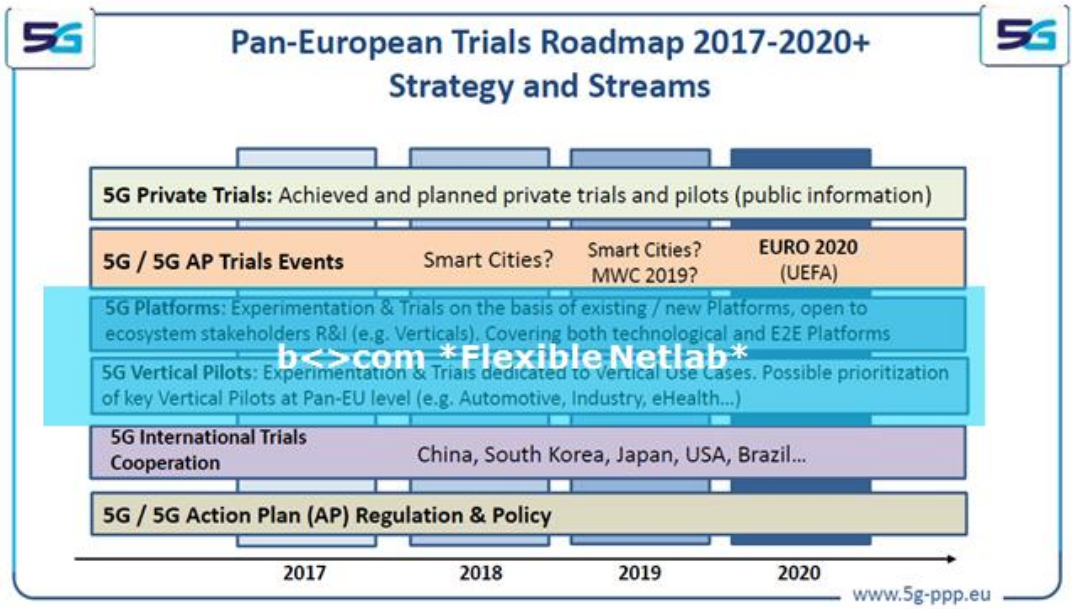

Figure 2: Positioning in Pan-European 5G Trials landscape and roadmap

3 Testbed business models

Various business models have already been identified in national and European studies (like PII - Pan-European Laboratory Infrastructure Implementation - project in 2011) and finally summarized in the table hereunder.

Type	Description	Identified Risks
Project Platform	Incomes: public subsidies, members fees Outcomes: investment in platform devices, run costs Target: dedicated to a specific project, for members only	Keep platform up-to-date
R&D Platform	Incomes: public subsidies, funded projects	Public funding dependency

	Outcomes: investment in platform devices Target: mainly academics (research), for collaborative projects	
Cluster Platform	Incomes: members fees, commercial service offer, public subsidies Outcomes: investment in platform devices, run costs Target: up-to-date R&D devices, test bed and user panels, private companies & academics	Access to platform to be prioritized Wide range of customers
Commercial Platform	Incomes: commercial service offer only Outcomes: investment in platform devices, run costs including marketing/commercial task force Target: Service offer including expertise & consulting, for public & private companies	Competition Ability to maintain the platform up-to-date

Table 2: testbed business models

In 2011, PII project statement was that the testbed market was not profitable:

- Initial investments in platform were huge and operational results are most of the time negative
- Most testbed platforms were subsidized by the government or regions (from 40% up to 100%) and they were considered as a leverage for the industrial policy in order to increase competitiveness
- Only project platform could reach a financial balance with collaborative project funding being an important part of their revenues (up to 60%) but this could also be considered as subsidies as the European Commission, a national government or a region can fund collaborative projects.

In 2016 and within 5G perspectives, this statement remains partially true, with following new inputs:

- Considering massive “cloudification” of 5G solutions, the “hardware” investment could be lower, based on hosting capacity renting with a lower TCO (Total Cost of Ownership) than dedicated hardware
- The part of open source, which in some cases can be considered as de-facto standards, is important in the telecom industry. OpenStack for Virtual Infrastructure Manager, OpenDayLight and ONOS for SDN controllers, Open Source MANO for VNF orchestrator are examples of such open source success. This could have a positive impact on the software license fees to operate a 5G testbed. Nevertheless, this could be counterbalanced by the cost of operation of such open source solutions, especially if the testbed relies on an upstream release (and not a qualified but commercial distribution). For example, the TCO of an OpenStack private cloud was higher in 2015 than a VMWare one’s due the scarcity of skilled OpenStack engineers. That is the reason why it must be stressed in our analysis that the TCO model shall encompass:
  - Hardware, with Acquisition and Maintenance
  - Software, with Subscription or Licenses and Maintenance

- People, with Hiring and Training costs

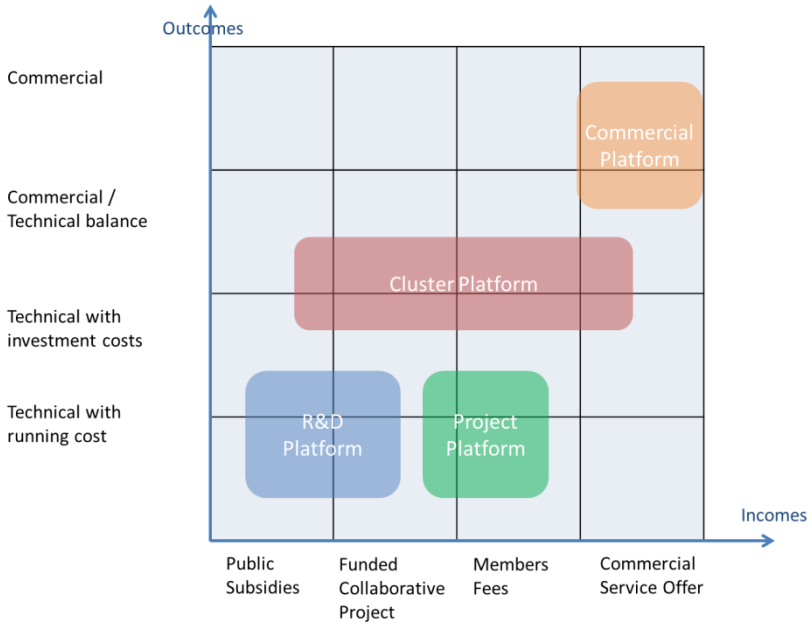

Figure 3: Business Models versus incomes & outcomes

4 5G Testbed competitive landscape

Networld 2020 ETP has issued in December 2015 a white paper on “5G Experimental Facilities in Europe” (refer to [5]). From this survey and taking into account that an end-to-end integration (including outdoor radio access network) is required to provide a 5G testbed, a list of major testbeds has been selected as key players for 5G experimentation with an end-to-end integration perspective.

This document is addressing a list of 7 testbeds (5GTN by VTT, 5G Playground by Fokus Fraunhofer, 5TONIC by IMDEA, BiO by Bristol, Adrenaline by CTTC, EANTC) and includes b<>com * Flexible Netlab * which is the proposal by b<>com for a sustainable testbed derived from 5G-ENSURE project. The 7 testbeds have been selected by 5G-ENSURE partners as the European most competitive ones in various business model categories.

4.1 5GTN

4.1.1 General Description

According to [6], “5GTN is part of 5thGear program by Tekes (the Finnish Funding Agency for Innovation)” and is located in Oulu, Finland. The second phase of the project, 5GTN+ is a continuance to the 5GTN. It is part of the 5GTNF (5G Test Network Finland) program that coordinates and combines the research and technology efforts. The testbed is located at premises of VTT and University of Oulu, Finland. The project is led by VTT and University of Oulu including the following entities as members: Anite, Bittium, Caritas, Centria, Elisa, Eltel, Esju, Exfo, Haltian, Hartela, Indalgo, Jutel, Kaltiot, Keysight, Mediatek, Nokia, Oulu University of Applied Sciences, BusinessOulu, Polar, Pulse Electronics, Pehutec, Sarokal Test Systems, Verkotan, Finnish Communications Regulatory Authority, Yle, as well as University of OULU.

5GTN is one of the key assets provided by VTT as a testbed node in the scope of 5G-ENSURE project.

4.1.2 Technical Description

5GTN provides a research platform facility for R&D and testing in realistic 5G network environment with real life performance. The full-scale version will support 5G devices with high frequency bands, cognitive management functionalities and system testing tools. The actual 5GTN is divided into two parts: The first one is a restricted part located at VTT (Oulu) for companies to test their technologies, tools and applications in a controlled environment. The second part is located at the University of Oulu allowing more public access to the test network. This allows large-scale deployment and testing of the user devices. Furthermore, the test network will also cover different parts of Finland for long-range field testing. Also, as depicted in Figure 4: 5GTN testbed, combining the test network with other 5G test networks is one of the future deployments. In addition, it is already connected to the 5G-Ensure testbed that combines VTT and b<>com network infrastructures.

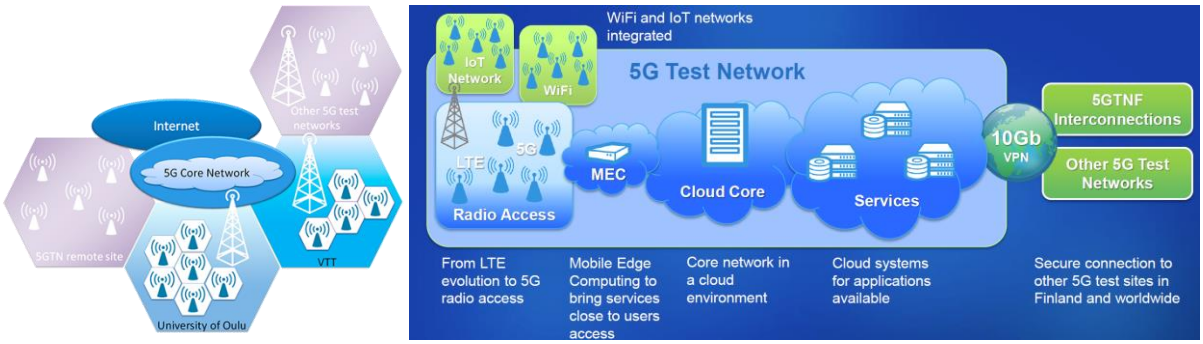

Figure 4: 5GTN testbed

4.1.3 Business Model

5GTN includes different network services, such as

- Support and consultancy
- Research platform allowing testing applications
- Business opportunities and development for new operator business models
- Possibility for long-term co-operation for customers

It is interesting to mention that there is an "open" access for interactive co-creation and "restricted" access for "controlled and confidential environment". However, the results are fully owned by the customer meaning that they are not exploited by the test network owners.

5GTN seems close to a "cluster platform" business model, with membership, cooperation between industrials and academics but also ecosystem openness. Basically, access to the test network is free, but naturally it demands the access device / SIM card, which is not free. Access fee for using the 5GTN in the "restricted" part depends on the use case: tailoring the network part for the tests, needed work force for completing the tests and possible outcome of the results. Average amount of yearly investments costs is between 100 k€ and 1 M€.

4.2 5G Playground

4.2.1 General Description

5G Playground has been setup and is fully operated by Fokus Fraunhofer. It is part of a global testbed named 5G Berlin (see [7]) which is backed by local and regional authorities and implies other players like Vodafone, Deutsche Telekom and Technische Universität Berlin.

4.2.2 Technical Description

According to [8], the testbed provide a network environment based on commercial components but also major building blocks designed by Fokus Fraunhofer, including:

- "Open5GCore representing a new scalable, low delay and highly reconfigurable approach to core networks
- OpenSDNCore addressing backhaul related features,
- Open Baton addressing NFV orchestration and
- Open5GMTC addressing the connectivity of a multitude of devices"

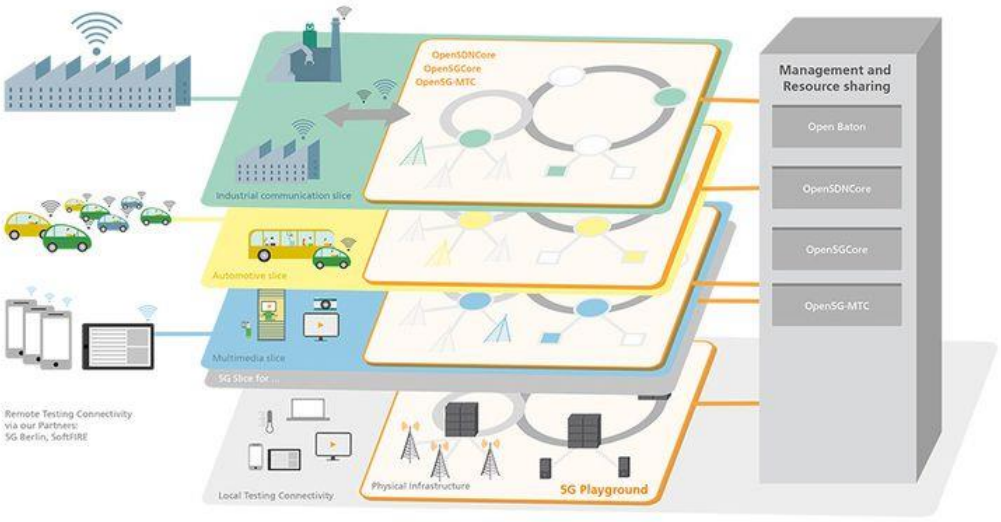

Figure 5: 5G Playground testbed

4.2.3 Business Model

5G Playground testbed business model looks like a "R&D Platform", with a high maturity level, due to the fact that Fokus Fraunhofer is a key player for years now and is delivering components to the industry with high TRL 5 Technology Readiness Level). There is no true "service offer" but Fraunhofer FOKUS is "actively searching for operator, vendor or academia partners, interested in building-up of the emerging 5G ecosystem".

4.3 5TONIC

4.3.1 General Description

5TONIC has been founded by TELEFONICA and IMDEA NETWORKS and is based in Madrid: according to [9], "the objective of 5TONIC is to create a global open environment where members from industry and academia work together in specific research and innovation projects related to 5G technologies with a view to boost technology and business innovative ventures. The laboratory will promote joint project development and entrepreneurial ventures, discussion fora, events and conference sites in an international environment." The testbed also includes the following entities as members: Ericsson, INTEL, COMMSCOPE, Universidad Carlos III de Madrid, Cohere Technologies, Artesyn Embedded Technologies.

4.3.2 Technical Description

Focusing on NFV/SDN functionalities, the testbed includes hosting and switching capacity for NFV infrastructure. It does not yet include outdoor Radio Access Network. The testbed is under IMDEA Networks institute umbrella, with operation staff from Telefonica and Universidad Carlos III de Madrid.

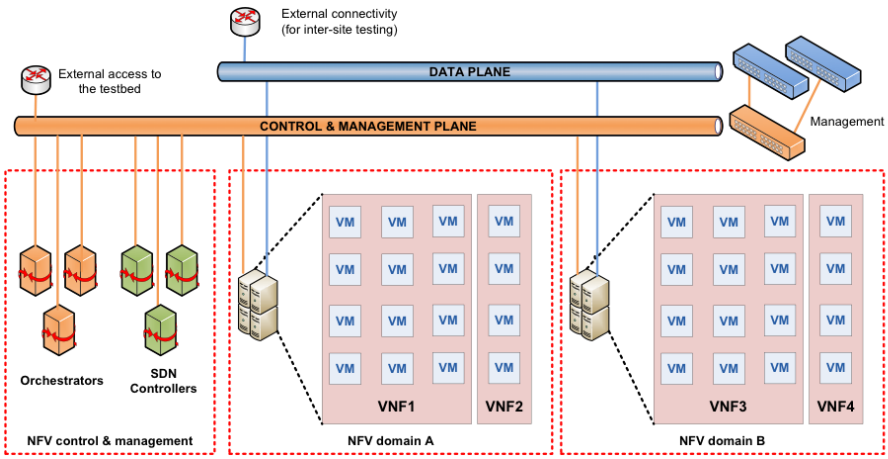

Figure 6: 5TONIC Testbed

4.3.3 Business Model

5TONIC seems to be a mix of "Project Platform" and "cluster platform" business model, with membership, cooperation between industrials and academics but also ecosystem openness with startups' contest. According to [10], its access is "commercial fee based (not for profit)". Average amount of yearly investments costs is between 100 k€ and 1 M€, mostly by members.

4.4 BiO

4.4.1 General Description

BiO has close links with the University of Bristol, but it is registered under its own company registration number. According to [11], BiO is "a joint venture between the University of Bristol and Bristol City Council. It is funded by the local, national and European governments, with academic research funding, and by the private sector". It includes industrial partners as NEC, InterDigital and Nokia.

4.4.2 Technical Description

BiO is not focused on 5G but it turned Bristol into a Smart City experimental site including users (it may be also considered as a Living Lab), data collection, and various access networks including IoT and core networks.

Figure 7: BiO testbed (Bristol is Open)

4.4.3 Business Model

The business model seems close to a “cluster platform” business model.

4.5 Adrenaline

4.5.1 General Description

The ADRENALINE testbed is operated by CTTC and encompasses multiple interrelated although independent components and prototypes, to offer end-to-end services, interconnecting users and applications across a wide range of heterogeneous networks technologies for the development and test of 5G services.

4.5.2 Technical Description

Different components span IT and networking domains, and allow researchers, system vendors and operators to evaluate experimentally, in conditions close to production systems, all aspects related to cloud computing in distributed environments with multiple geographically split data centers, while jointly managing storage, computing and networking resources.

As mentioned, in the all-interconnected context in which end-to-end 5G services may span heterogeneous cloud-computing and networking technologies, ADRENALINE includes an SDN Integrated IT and Network Orchestrator (SINO). A SINO is a centralized system able to coordinate, from a high-level view, cloud and network service management aspects in modern multi-tenant environments which provides the platform to run user applications and virtualized network functions (VNF Manager). A NFV orchestrator is also provided in to deploy end-to-end VNF through VNF Forwarding Graphs. The Cloud Computing service manager is implemented in terms of a modified OpenStack software, one of the top open-source distributed cloud computing systems.

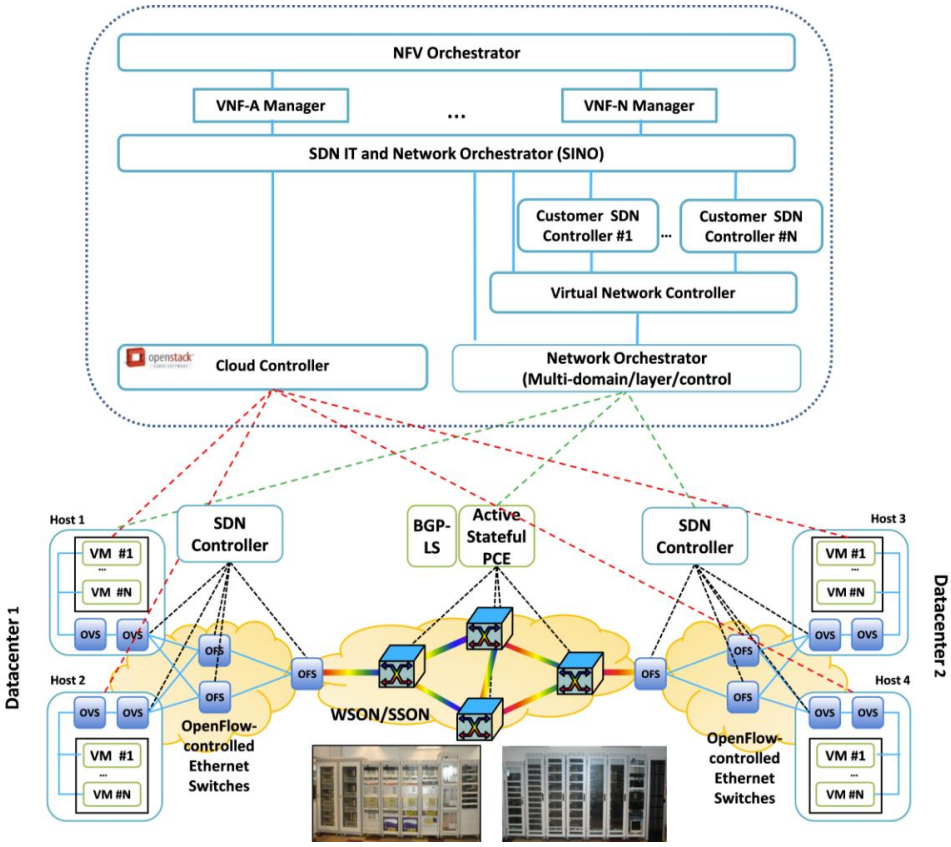

Figure 8: Adrenaline Testbed

4.5.3 Business Model

Adrenaline testbed is funded by CTTC so it can be considered as a "Research Platform".

4.6 EANTC

4.6.1 General Description

EANTC is independent test lab based in Berlin (Germany), which originally spun off from the Technical University of Berlin (TUB) in 1991 and has kept closed links with TUB. According to [12], EANTC focuses on network performance test including interoperability and conformance testing.

4.6.2 Technical Description

There are few publically available documents about a technical description but EANTC is building on-demand test environment for customers. EANTC is targeting network security infrastructure testing including DPI, IDS/IPS, firewalls, IPSec VPN …. The key asset of EANTC is not an existing platform but the skills in testing methodologies.

EANTC maintains a lab infrastructure with the New Ip Agency (NIA, refer to [13], "*a not-for-profit independent initiative providing information, education, analysis, community services and testing to support and accelerate the development of a global economy based on open, advanced, virtualized IP networks*") and performs NFV interoperability testing. For those NFV plug test session, according to [14], some NFVi vendors provided following assets:

- "*Cisco NFVi provided a full OpenStack deployment, including three redundant control nodes, three compute nodes, a redundant storage system, two build nodes and a router, plus a switch connecting the infrastructure internally until May 2016.*
- *Starting in October, EANTC installed a Dell EMC NFVi. It is a full OpenStack environment, with three redundant control nodes, three compute nodes, three storage nodes, one platform manager, one control node and three switches (two leaf switches and a management switch). It also includes Dell EMC hardware element managers for deployment and management of the infrastructure.*
- *Huawei provided FusionSphere with three hot-standby control nodes. The FusionSphere installation was upgraded in the summer and returned to EANTC with new hardware.*
- *Juniper provided one Contrail server until April 2016 which implemented the OpenStack environment using the virtual deployment option: One virtual control node, one virtual compute node and a virtual router. This satisfied the minimum testing requirements in the first phase.*
- *Nokia CloudBand provided a full OpenStack deployment for the whole year (three control and eight compute nodes including local storage, plus a router for internal connectivity).*
- *ZTE provided Tulip Elastic Cloud System (TECS) from April onward. The TECS environment is a full OpenStack deployment using local storage to meet the NFVi testing requirements.*"

Figure 9: EANTC testbed (with NIA members)

4.6.3 Business Model

The model seems to be a "commercial platform", targeting ISPs (Internet Service Providers), carriers and large business companies. EANTC claims to be vendor neutral and grants confidentiality in the testing results.

4.7 b<>com * Flexible Netlab *

4.7.1 General Description

* Flexible Netlab * is a multi-tenancy dedicated environment, taking benefit from some key corporate resources like a private cloud infrastructure provided by b<>com Institute of Research and Technology. It is dedicated to the telecommunication field of innovation, especially with the 5G perspective, for the

instantiation of operational platforms for experimentation. * Flexible Netlab * could be seen as a framework capable of instantiating many 5G-capable infrastructure tenants. Each tenant is autonomous and can apply the NFV/SDN principles as defined by the ETSI with the slicing and security concepts promoted by 5G architecture.

The framework is provided with orchestration tools allowing for the instantiation and management of the configuration of the instances running in the environment. The framework is connected to the corporate indoor and outdoor RAN (either Wi-Fi, LTE advanced, IoT including LoRa) allowing radio resources booking during test sessions. It is also connected to corporate tools that provide basic features like AAA and network services but also advanced services like test session management which grants a permanent storage for test logs and session outputs.

4.7.2 Technical Description

On top of the infrastructure, b<>com provides also VNFs based on in-house developments or supplied by members or partners as well as elements generated by Open Source communities like OpenAirInterface (refer to [15]).

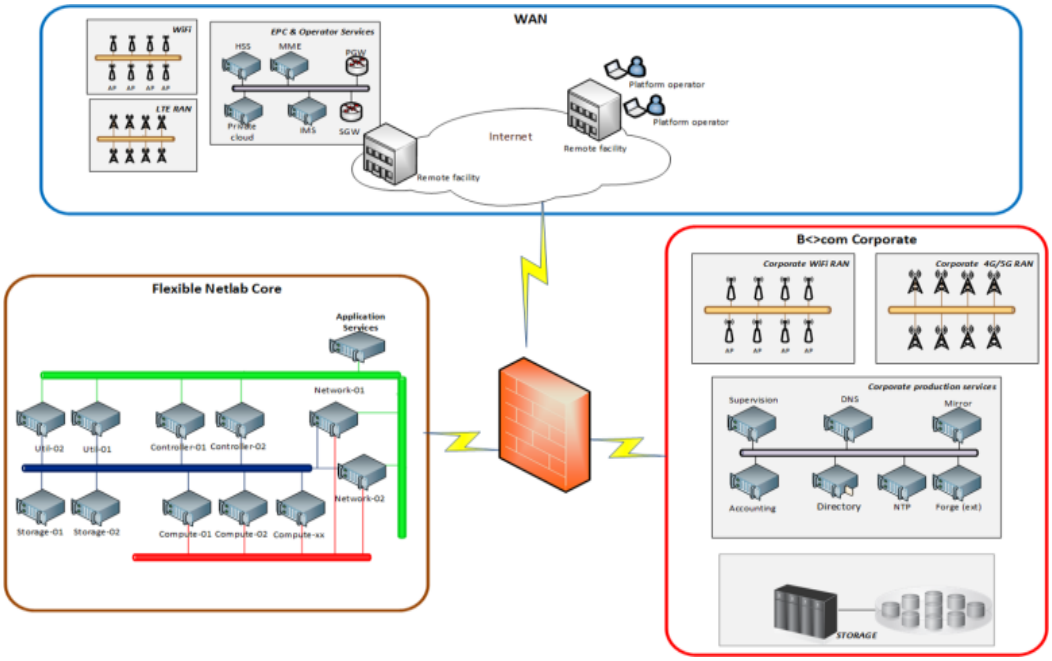

Figure 10: b<>com *Flexible Netlab* testbed

The technical challenge was to provide an environment that fulfils the hosting requirements for security enablers in the scope of a collaborative project, so including different testbed nodes and remote access to users.

4.7.3 Business Model

b<>com is a non-profit private research institute and is an example of Public-Private Partnership in France. * Flexible Netlab * has first been built to fulfil the requirement of b<>com in-house R&D projects. With 5G-ENSURE H2020 project, * Flexible Netlab * reached another step of its model, by opening the access to European partners. The challenge was to diversify the incomes with European funding, not for investment

but for operational, having in mind a critical mass for such activities. The ultimate target will be to open a commercial access as soon as the testbed is stable enough to cope with requirements from the industry or service. So * Flexible Netlab * started with a mix of “R&D Platform” and “Project Platform”, willing to move to a “Cluster” and even “commercial” platform.

4.8 Summary map

As a summary of above mentioned testbed, the figures hereunder provide a summary of the competitive landscape of 5G testbeds in Europe. It would be interesting to investigate also in APAC & US geographical areas but this not included in this document edition.

4.8.1 Testbed technical features

For competitive analysis, 5G-ENSURE has selected the following criteria to evaluate the testbeds and provides a radar chart:

- Cloud NFVi: availability of a cloud infrastructure in order to host NFV
- NFV: availability of a catalogue of VNFs (Virtual Network Functions) and potential PNFs (Physical Network Functions)
- Backbone: ability to provide backhauling, fronthauling and interconnect the testbed with other testbeds
- 3GPP RAN: availability of an outdoor 3GPP Radio Access Network. This implies to get frequencies and agreement from the national regulator or to have a deal with a mobile operator.
- non 3GPP RAN (IoT, WiFi, …): availability of indoor/outdoor Radio Access Networks on non-licensed spectrum like WiFi, IoT (ISM Band with LoRa, Sigfox, …).
- Open Source: Does the testbed mainly rely on open source software?
- Carrier Grade: Does the testbed mainly rely on carrier grade solution provided by telco suppliers?
- Living Lab: Does the testbed provide also Living Lab activities?
- Test method. & tools: Does the testbed provide also a bunch of testing tools with methodologies in order to promote Continuous Integration / Continuous Deployment?

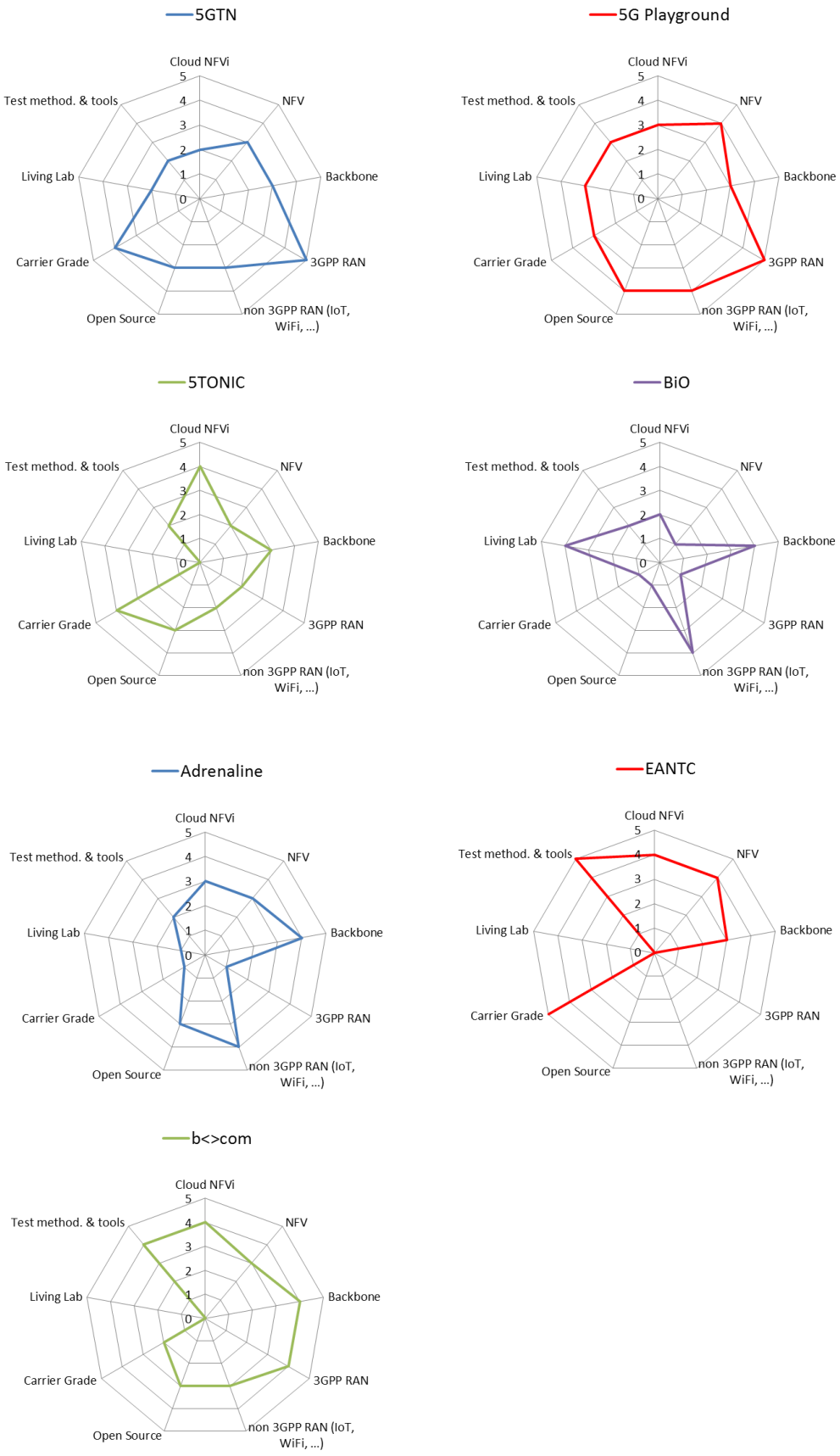

Figure 11: Testbed technical features radar chart

4.8.2 Business Models

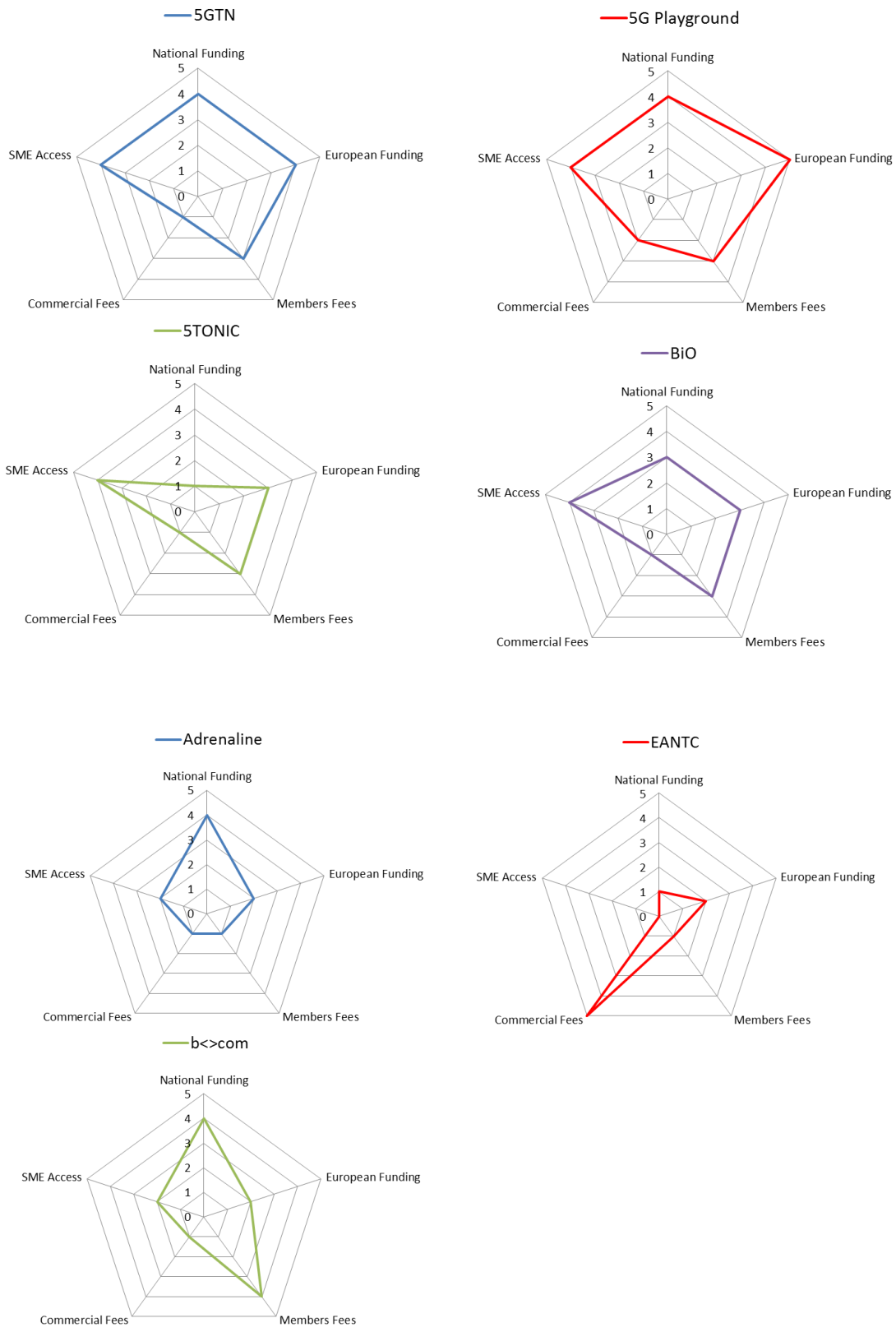

Figure 12: Testbeds incomes radar chart

As a conclusion of the competitive landscape analysis and business model positioning, the figure hereunder provides a snapshot of the testbeds that have been addressed in this document. b<>com *Flexible Netlab* is quite at the heart of the picture: that means that the recommendation is to base the testbed on a mix of incomes from public funding to commercial revenues. One of the challenges is to keep differentiators with similar testbeds like 5G playground by Fokus Fraunhofer, 5GTN by VTT or 5TONIC by Telefonica and IMDEA Networks, or to build some alliances with them in order to build a Pan-European testbed for 5G.

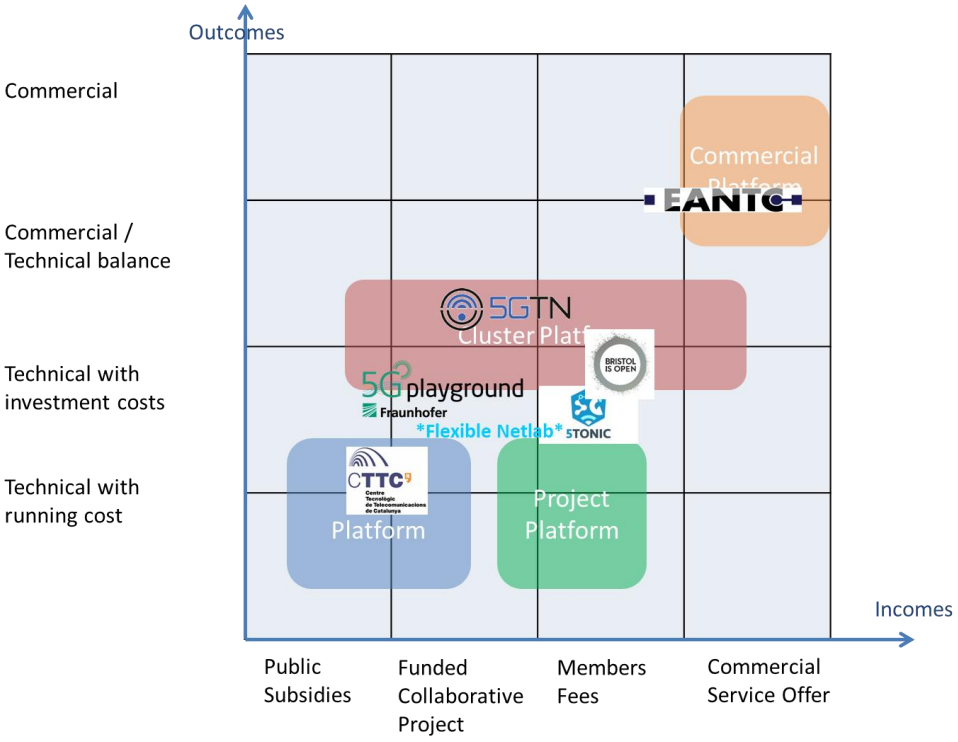

Figure 13: 5G Testbed competitive landscape

5 Testbed operation plan

5.1 Key Partners

Local, Regional, National and European authorities are key partners to setup and operate a sustainable testbed activity:

- Testbed can be perceived as a show-room of the key competences of a territory (a city, a region, a country)
- The pulse to setup a testbed is most of the time initiated by a public authority in order to boost an ecosystem, looking for a virtuous loop involving large business companies, academics and SMEs including start-ups.
- That is indeed the case with 5G and Cybersecurity which are two major pillars of European research programs, backed by two Public –Private Partnerships, 5G-PPP (refer to [16]) and ECSO cPPP (refer to [17]).

With public authorities, large business companies are the second category of founding organizations to build a sustainable testbed:

- Telco manufacturers can provide key assets, including hardware and software building blocks for the testbed as well as skilled manpower to design and operate the testbed.
- Telco operators can provide also tangible assets like hosting and networking capacities as well as antenna sites as well as intangible assets like network operation authorization. They can also contribute to design a testbed which is in line with future commercial networks.
- Vertical domain players can provide the playground with the use cases in order to convert them into business case for the ecosystem.

With its consortium, 5G-ENSURE project includes such players:

- Telco manufacturers: Ericsson is in the consortium but is not involved in the testbed activities. On the contrary, Nokia is involved in the testbed activities and shall provide a node to be interconnected with VTT and b<>com.
- Telco operators: Orange has been deeply involved in the testbed activities by piloting the dedicated Work Package and providing its know-how in terms of security.
- In phase I, there was no vertical domain player in the consortium.
- Both VTT and b<>com are non-profit but private research institutes. They are both providing close links with two national ecosystems, respectively Finnish and French ones, and so with regional and national authorities. This is crucial to avoid any overlapping with other national initiatives, at least in those two countries.

We will see in chapter 5.4 with the opportunity to focus on Security, National Cybersecurity Agency and licensed ITSEF could be key partners.

5.2 Key Activities

After requirements' collection and initial testbed setup, the heart of the activity is for sure to operate the testbed, including maintenance and user support. This is the case for 5G-ENSURE project with at least 4 partners involved in those activities:

- Orange as a leader of the Testbed activities, providing its view on Telco operations and security expertise,
- b<>com as the main contributor and providing a Core Testbed node,
- VTT as key player in testbed activities, providing a Testbed node
- Nokia, providing a Testbed node with the strategic vision of a Telco manufacturer

Inside 5G-ENSURE project, the Testbed Terms of Use have been established with the contribution of legal departments of the partners (refer to [18]). If this document correctly addresses the use of the testbed by 5G-ENSURE partners, it did not solve how to open the access to other 5G-PPP projects and external customers. The Testbed Terms of Use have been built under the 5G-ENSURE Consortium agreement and 5G-PPP Collaboration agreement: that makes this document quite simple and efficient because it avoid to define again all the Intellectual Property and Confidentiality rules. Opening the access to external partners and/or customers would require building a standalone agreement covering also those items. This is quite complex in the context of a project consortium but would be much more easy to achieve if the testbed is operated by only one legal entity. As the main contributor to the establishment of the 5G-ENSURE Testbed Terms of Use, b<>com, with * Flexible Netlab* and as a single legal entity in charge to operate the testbed, will be in position to sign a new edition of the Terms of Use with any new party interested in using the testbed service offer. Of course, the new party could be any partner of a 5G-PPP Phase II project. In any case, legal activity is pivotal to establish the rules with the dues and duties.

Last but not least, the testbed MUST include Business Development activities. 5G-ENSURE project scope provides a certain level of backlog but this level does not make a business plan for a testbed service offering.

5.3 Key Resources

The first types of key resources are:

- The technical infrastructure on which the testbed can be built: for 5G-ENSURE, the testbed is built in two nodes, provided by two partners, i.e. VTT and b<>com. The investment that financed those assets was not in the scope of 5G-ENSURE H2020 financial funding. It is important to underline that the 5G-ENSURE H2020 budget for infrastructure was rather limited: 5 k€ for VTT, 50 k€ for b<>com. An estimation of budget for technical infrastructure is done at chapter 5.8, taking into account some constraints and hypothesis: for confidentiality reasons and operation constraints (cost of network interconnection with public cloud), the testbed has to be built on a private cloud, not a public one like AWS or OVH.
- The know-how to setup and operate a testbed. The required profile is close to “DEVOPS”, such engineers are providing a bridge between Research & Development on side, and Operation on the testbed for the other side. As mentioned above, those profiles needs to master Open Source solution in order to avoid expensive software solution and such profiles are scarce.

But other types of resources are also required to build a sustainable testbed with a stable incomes flow. Those resources should encompass:

- Legal competences in order Non-Disclosure Agreements, Collaboration Agreements, Terms of Use and Commercial contracts
- Business Development in order to promote the testbed, at national and European level in the collaborative projects, with also a marketing profile in order to build a competitive service offer on the European market

- Accounting for invoicing!

5.4 Value Propositions

An analysis of Figure 11: Testbed technical features radar chart shows that 5G-ENSURE and b<>com * Flexible Netlab * provides some key differentiators:

- **Pre-5G End-to-end integration including various Radio Access Networks**
- **Testing tools and methodology**
- **Flexible and neutral Environment**

The value proposition is to provide to the European industry a pre-5G testbed for end-to-end integration, based on a virtualized and flexible environment with a focus on security. As a research institute and operating the testbed with its own staff, b<>com can be considered as neutral even if Orange and Nokia are at the board of the institute.

Focusing on security, the ultimate value proposal would be to link the testbed offer with products' certification. This would imply to build a partnership with an ITSEF (Information Technology Security Evaluation Facility), i.e. CESTI in French, which is labelled by the national Cybersecurity agencies, i.e. ANSSI in France. b<>com would be ready to establish a deal with an ITSEF based on revenue sharing.

For example, the list of the licensed ITSEF by ANSSI in France is available here [19].

5.5 Customer Relationships

Here we will distinguish pre-sales and after-sales communication.

For pre-sales, the testbed activity needs a strong brand policy. For example, b<>com has chosen to brand its 5G testbed activity as **b<>com * Flexible Netlab ***. This activity has already advertised in 2017 under the 5G-ENSURE flag during the FIC (Forum International de la Cybersécurité in France) and also during the MWC in Barcelona. This communication will be enforced in 2018 under b<>com flag with a detailed service offer.

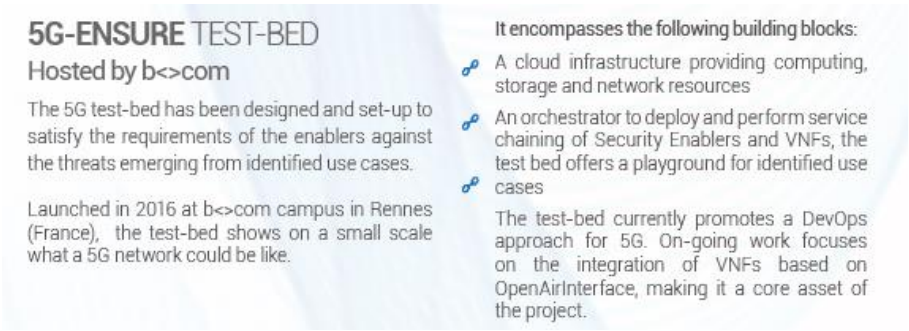

Figure 14: extract of 5G-ENSURE flyer

For support and after-sales, 5G-ENSURE testbed and b<>com * Flexible Netlab * include online support with ticketing in order to follow Customer Requests and Problem Reports.

5.6 Channels

The strategy is to address a part of the market directly, especially for collaborative project as b<>com and other 5G-ENSURE partners are well positioned to address Research & Development project managers. Outside collaborative projects, some national key accounts have been identified but most of them have

their own testbed environment. For such actors, there is still a possible interest based on differentiators with their own testbed features: security but also the ability to cross-connect two testbeds and provide some diversity in the implementation in order to address interoperability issues (between various Virtual Infrastructure Managers, between SDN controllers, between orchestrators …).

One part of the Business Development Strategy relies also on an indirect entry with the ability for the Commercial & Technical staff to build partnership with:

- Academics and private companies focused on training for professionals with hand-on session on infrastructure including Cloud and Radio Access Networks.
- Software and Consulting private companies would be interested to build their own testing offer service based on testbed (in such a case, testbed service offer will have to be reviewed in order to fit the software & consulting market prices). The ITSEF for products' certification is a subset of this category.
- Standardization bodies, Forum or Alliances which would be interested to use a referenced stable platform dedicated to test to promote interoperability, new services, fixe/mobile convergence …

5.7 Customer Segments

A segmentation to be considered is the size or type of the customer:

- Academic:
  - Academic entities are not ready to use external testbed services outside the framework of a collaborative Research & Innovation project. They have no budget for this and they cannot be considered as a customer target.
- SME:
  - Like 4G, 5G is perceived as an opportunity for SMEs to develop new services for telecom operators.
  - The average basket to address the SME market shall be in line with the R&D budget of such a company and this has to be considered as a "niche" market for a testbed: many SME will focus on application layer (not in the heart of network infrastructure impacted by the transition to 5G) and so will be keen to test in pre-commercial environments rather than on a testbed. A pre-commercial environment will enable possible partnerships with large companies like Operators and Telecom Infrastructure suppliers
- Large company: this segment remains the main target as testbed customers and an ability to invest in end-to-end integration and interoperability testing.

Another segmentation can be performed through the business areas:

- Application developers but as mentioned above, application developer will look for pre-commercial environments.
- Virtual Network Functions Developers and Physical Network Functions suppliers, in order to integration from an end-to-end perspective
- Security Enablers Developers
- 5G including IoT and security research community
- ITSEF (Information Technology Security Evaluation Facility) and their customers for product certification

5.8 Cost Structure

The cost structure can be split in following lines:

- Hardware: Acquisition and maintenance and running cost
- Software: Subscription, licenses and maintenance
- People with Operational Team (size of the team – FTEs - for 8x5 and not for 24x7 which is not in the scope) and Management / Business Development Team.
- Indirect costs for the organisation supporting the activity.

Table 3: Yearly budget gives an idea of the budget for a "Minimum Viable" testbed in term of sizing (resources including human resources with an operational team of 4 FTE): this budget is around 800 k€ per year. This has been calculated on financial hypothesis that are close to what has been experienced by b<>com during the last two years for a smaller team just in charge of internal and 5G-ENSURE project.

This has also been compared to the total cost of ownership of a private cloud based on OpenStack. This has been presented at last OpenStack Summit in Barcelona, October 2016, by Catalyst IT Ltd (refer to [20]) and is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License. A private OpenStack cloud is just a piece of a pre-5G testbed but this gives some inputs about the way to build the cost of such an infrastructure.

This 800 k€ figure was also the approximate budget of a 4G testbed named ImaginLab and which was operated by Images & Réseaux cluster (b<>com has been spun off from this cluster) in the 2010-2013 periods, even if the cost structure was a little bit different with a higher infrastructure cost due to COTS hardware equipment at that time. ImaginLab testbed did not manage to find a balanced business model with the end of its national funding and the high maintenance cost for telco grade equipment.

It is interesting to stress that more than 50% of the budget is due to engineering human resources and this is not a surprise because testbed activity is about servicing.

	Cost /year/unit	Units	Yearly	Comments
NFVi Cloud				
Example of a blade composed of: 1 x AMD Opteron(tm) Processor 4365 EE with 8 x 2Ghz cores 64 GB DDR3 RAM 128 GB SAS Hard Disk (Extensible with SAN/NFS mounts) 8 x 1 Gbps NICs Used by b<>com	1 575 €	**40**	63 000 €	Cost/year/unit is calculated by b<>com IT department and includes DataCenter with power/air cooling/security ..., acquisition cost for Network/Compute/Storage nodes, depreciation time for ICT hardware (usually 36 months), interconnection, ... Units based on 5G-ENSURE x 4 hypothesis, 5G-ENSURE currently using 10 blades for b<>com testbed node
RANs				
COTS WiFi AP	150 €	10	1 500 €	
COTS LTE EnodeB + UE	3 500 €	4	14 000 €	Based on an EnodeB + antenna around 10500€
COTS IoT Gateways + Endpoints	500 €	10	5 000 €	Based on a IoT GW around 1500€
SDR prototype	15 000 €	4	60 000 €	Based on USRP + Amplifier ....
Software & tooling & maintenance				
	50 000 €	1	50 000 €	Simulator like IXIA, Catalogue like Artefactory, ..
Operational team				
FTE for 8 hours x 5 day per week	83 500 €	**4**	334 000 €	Units based on 5G-ENSURE x 2 hypothesis
Management team (including Business Development)				
FTE	105 000 €	**1**	105 000 €	
Total Direct cost			**632 500 €**	
Indirect costs	25%		158 125 €	Indirect cost profile use din H2020 projects
Total Cost			**790 625 €**	

Table 3: Yearly budget

5.9 Revenue Streams

With a model trying to conciliate Research & Commercial platform, the scenario which is envisioned is to base the revenues of the testbed on a mix of revenues from:

- Funding by National research projects
- Funding by International (European) research projects
- Renting of the testbed for pre-5G end-to-end integration and experimentation
- Renting of the testbed for pre-5G security testing and revenue sharing for certification by ITSEF.

6 Sustainability focus

6.1 List of security enablers

The table of the security enablers with the terms of use on the testbed is available in document [21], which is a deliverable of the project. The availability of those enablers with the ability to deploy them on the testbed is considered as a key factor of sustainability for the testbed.

6.2 Testbed Users Satisfaction

5G-ENSURE testbed supported up to 50 users. The 5G-ENSURE project team carried out a user satisfaction survey by providing a questionnaire about the testbed service offer. The target was to get some feedbacks from the testbed users in order to have a status on it and to identify what has to be enhanced or added for its sustainability.

The survey was held during the last month of 5G-ENSURE project, for a two weeks period between the 25th of September and the 6th of October. The survey was sent by email to the list of declared 5G-ENSURE testbed users:

- 50 users were in the list
- 20 users attempt to fill the survey
- 15 users completed the survey (meaning that 5 did not succeed to submit all the answers) with a mix of researcher and engineer working for various types of organization (Research Institutes, Telecom Service Operator, Telecom Infrastructure Manufacturer)
- 13 out of these 15 users were “true” users, meaning that they use the testbed to deploy or evaluate enablers. Those 14 users all think that testbeds were useful in Research & Innovation H2020 projects, as long as the project aims the development of hardware/software components, especially if the project targets a transfer to the industry. The users do think that the testbed was useful in the scope of 5G-ENSURE project.
- The extra answers were however interesting:
    - One person was not in position to install or test software and that is the reason why he is not considered as a “true” testbed user. Nevertheless, he underlined that a testbed was “useful if properly maintained as a stable facility”, so the sustainability challenge is a key one.
    - The other one could not connect to the test-bed partly due to partner security policy. This is an issue that the testbed cannot solve.
- The users were asked to give a grade between 1 (Highly Dissatisfied) and 5 (Fully Satisfied) to 11 criteria. The overall results are quite good (near “satisfied” for all the criteria) for the 5G-ENSURE testbed (see Figure 15: Testbed Evaluation). Nevertheless, the deviation for some criteria like “usability”, “helpdesk” and “tooling” is huge. According to the feedback, attention must be paid to:
    - Email notification with Helpdesk tool
    - Evaluation process too complicated
    - Some tools were considered as too complex and not intuitive (TestLink was mentioned)
- Note that there was a possibility to choose to stay anonymous or not, in order to get more transparency in the evaluation.

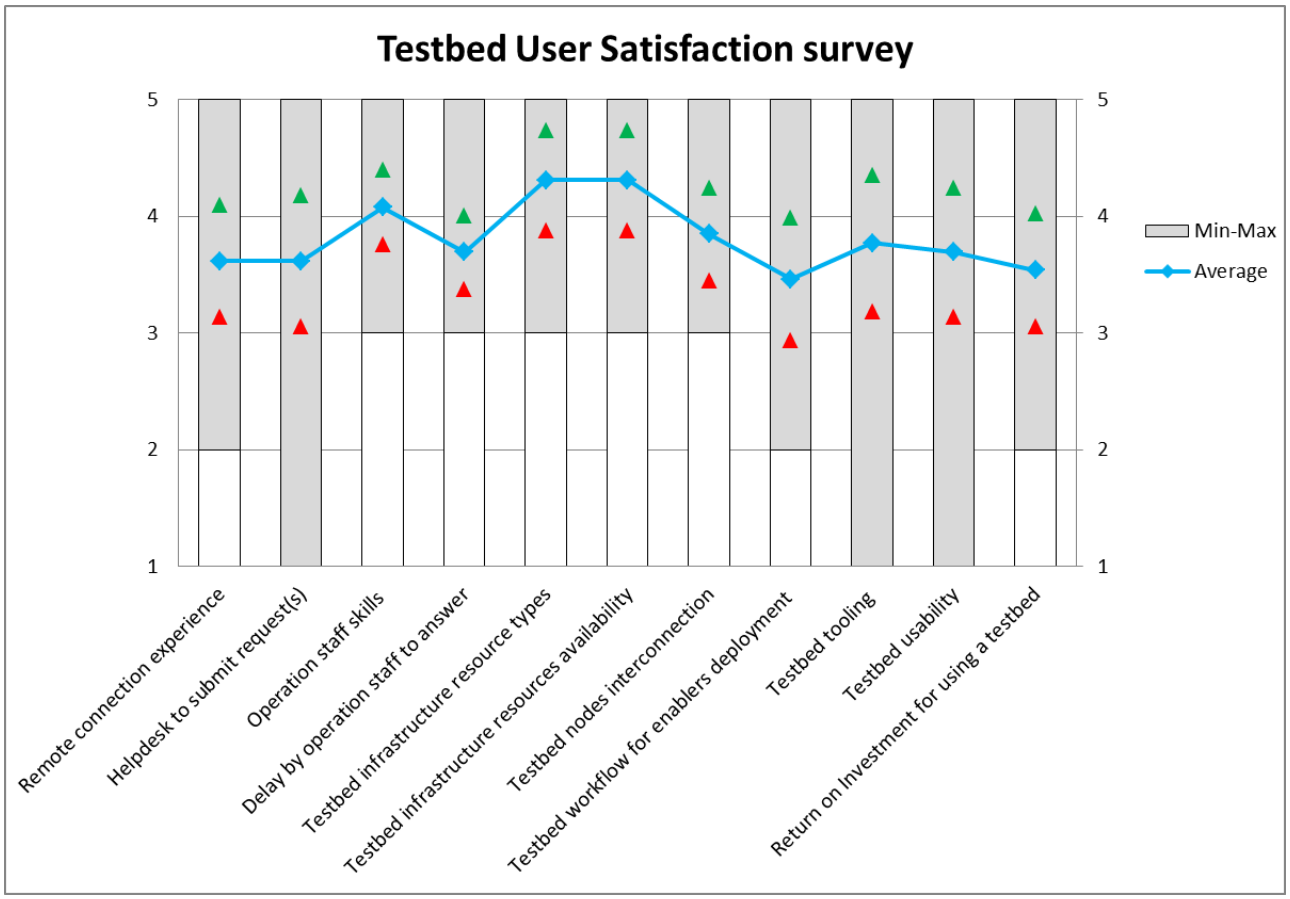

Figure 15: Testbed Evaluation

Finally, users were asked to suggest possible enhancement or new features. The table hereunder gives a list (with the verbatim from the users) of what could be enhanced in the testbed.

Id	Enhancement proposal	Testbed operator feedback
1	Helpdesk sent too many email notifications.	The workflow can be customized. The current one was the default setting of the ticketing open source tool. It can be reviewed and adapted accordingly.
2	Time slots should be more flexible.	It has been decided to align testbed operator support with partners opening hours. Even if the testbed is targeting telco grade quality, the business model is not compatible with a support outside opening hours.
3	Documentation, tutorials about the TestBed.	The documentation exists, training has been done during workshops and those sessions have been shot in video in order to be available on the project wiki for those who missed the workshops.
4	Tools for monitoring the available capacity.	The tools exist but are in the hand of the testbed operator team. It is not the role of the testbed user to monitor the testbed infrastructure capacity.

5	This environment was considered by one user as too restricted for this kind of research project. When you are serving this kind of cloud infrastructure for your paying clients, then the restrictions are required.	The user noticed himself in the follow-up of the comment: the practise in Research & Innovation may differ from a production infrastructure. Nevertheless, 5G is promoting DevOps approach and if the 5G-ENSURE project aims to deliver enablers with high TRL levels, the testbed engineering rules must apply.
6	Excellent experience, for the most part, with two minor remarks when it comes to: 1. Remote connection experience but no Internet access when connecting with the VPN, but the issues involved are understood. 2. Testbed tooling - Artifactory was somewhat of a learning curve and the structure is not very straightforward, but mostly OK	The point that is interesting to stress here is the following one: it is normal to have a learning curve as 5G-ENSURE project has set new processes and new tools coming from IT.
7	Some of the Testbed processes also tools may need to be revisited and/or further improved based on feedback received from users (ranging from Enablers Owners and/or participants to joint process defined). I think it is very important to learn from usage and mature accordingly both the tools and processes. This is key to make the testbed be widely adopted beyond the project as targeted. Also it is important to keep things flexible, interoperable and evolvable (as it has been so far) to further attract and develop community of testbed users.	The target of this survey is to gather these users' feedback and share these outputs inside the project in order to improve the testbed with the future extension.
8	A user asked for a radio accesso network.	There are multiple answers to this question. First, 5G-ENSURE does include radio access networks, even different types with WiFi access network but also LTE access network thanks to Nokia testbed node deployment. Secondly, during the requirements collection among the enablers' development, the need for a radio access network was required by only one enabler (enhanced privacy capability) and the implementation which was selected by enabler owner was based on a WiFi access network.
9	Testbed should deploy some other elements (soft and hardware) to allow use case validation.	Testbed deployed all the elements that have been requested during the requirements collection phase.

10	New Tools for traceability and coordination / synchronization between the testbed tooling offers	The tooling of the testbed is based on open source solutions, so it is not an integrated solution. Nevertheless, it is possible to share cross references like a ticket id for example. Moreover, one of the key topics of TestLink is to provide traceability between test cases, test plan, threats to be covered and test sessions.
11	More vpn options e.g. OpenVPN.	The choice of the tools is a matter of efficiency especially regarding the interoperability possible issues and the support to be provided. That was the reason for a limited VPN options. So far, it has not been a blocking issue.
12	The web based request system could be a bit simpler to use.	See item n°1
13	The global infrastructure is very good and secure through the VPN. Also the repository is a good place to leave all the prototypes together.	5G-ENSURE testbed provides a repository for enablers based on Artifactory tool. This is indeed a DevOps good practise and the selected solution grants a stable and secure access to the enablers packages delivered in the scope of 5G-ENSURE project.

Table 4: Possible enhancements for testbed

7 Extension Plan

7.1 Marketing & business scope

For marketing and business scope, the recommendations are mostly detailed in chapter 5 with the key partners to be involved, the segments to be addressed and the channels to get in touch with the possible stakeholders.

7.2 Technical scope

7.2.1 Vertical Domains

Extension plan shall address the needs of vertical domains like Industry 4.0 and so the testbed must include experimentation facilities to cover such requirements, based on the 5G-ENSURE testbed first instantiation, which could be enhanced with additional nodes and features.

For example, 5G-PPP Phase II project are addressing proofs of concept, which means that an end-to-end integration must be performed including VNFs (Virtualized Network Functions), security enablers (coming from Phase I projects such as 5G-ENSURE and 5G-PPP phase II projects) and also Industry 4.0 playgrounds.

7.2.2 End-to-end integration

The first consideration, and that's a strong requirement for phase II, is that end-to-end integration means that partners have to agree on a unique integration framework and the role of integration in that framework must be clearly identified. An open source framework like OpenAirInterface (OAI) alliance is a possibility but other frameworks could be provided especially by telco manufacturers.

7.2.3 Industry 4.0 requirements

If 5G targets Industry 4.0, "future communication solutions are expected to ensure connectivity between different globally distributed production sites and new actors in the value chain (e.g. suppliers, logistics) seamlessly, in real time and in a secure way", according to 5G-PPP. "The 5G system will be relying on a dynamic and flexible function allocation and configuration and 5G networks will highly rely on software networking, virtualization and slicing techniques."

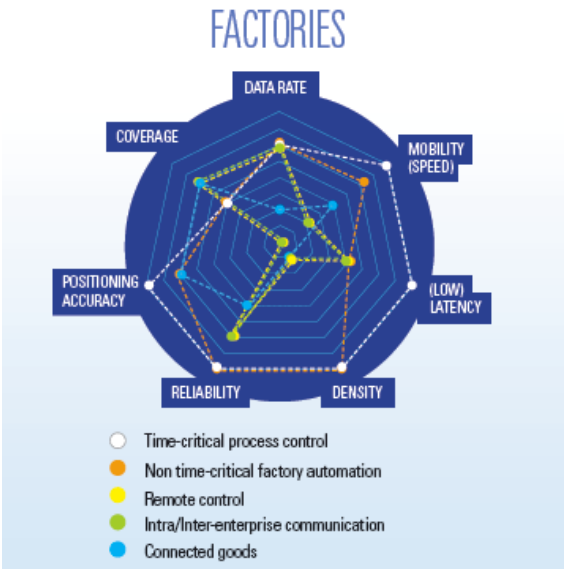

Figure 16: Factories capabilities and requirements spiders chart

As may be seen from Figure 16: Factories capabilities and requirements spiders chart, the testbed must provide some key features like the following ones:

- Slicing (see Figure 17: multi-slices architecture) to deliver a specific Quality of Service in line with vertical domain's requirements. The testbed shall anticipate how slicing will be defined, per QoS, par macro-service (Multi-Media Broadband, IoT, Critical Communications, …), per vertical domain (automotive, energy, health, industry, …). However, the testbed should specify how slices are orchestrated consistently along the whole chain (radio access, core network,) in a secure way and how slices are mutually isolated.
- More than a virtualization (Network Functions and Security enablers), a "cloudification" of Network Functions which need to be massively distributed on a Cloud Infrastructure.
- Industry 4.0 Experimental Playgrounds (at least 2 to deal with sites distribution use cases) for Factories field trials (see Figure 18: Testbed extension).
- Ability to deploy Edge Computing resources (Cloud infrastructure near to the Industry 4.0 Playground, hosting Network Functions and security enablers in order to minimize latency and fulfil real time constraints)
- Security-as-a-service model that can offer possibility to companies for testing their services against
  - Micro-segmentation
  - Authentication and access control
  - Security monitoring
  - Privacy
  - Trust metric

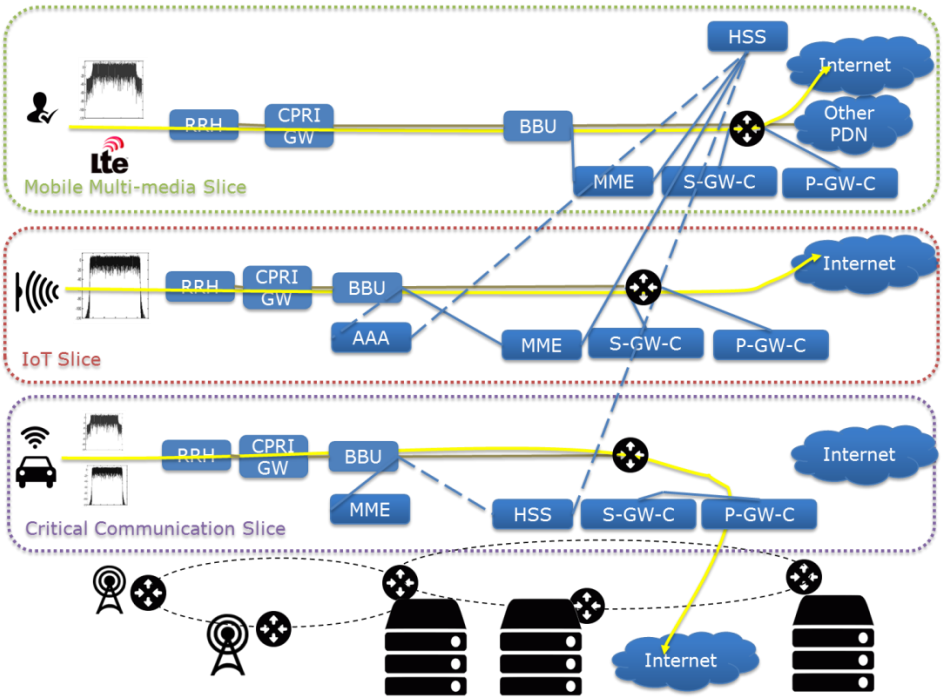

Figure 17: multi-slices architecture

The Industry 4.0 Experimental Playgrounds may provide various technologies:

- Non trusted non-3GPP access network , like:

- Legacy Wi-Fi private networks with AAA authentication
- New upcoming private LoRa networks with Over-The-Air activation procedure
- Legacy technologies still used in some industrial vertical domain like W-MBUS

- Trusted non-3GPP access network, like Wi-Fi with EAP-AKA/AKA' authentication
- Trusted 3GPP access network, like LTE-M or LTE-MTC (Machine Type Communication)

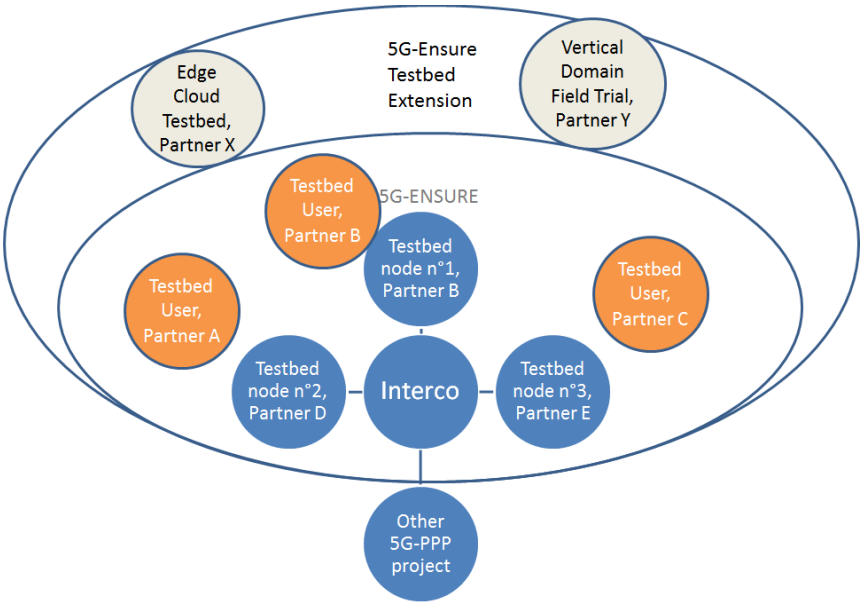

Figure 18: Testbed extension

The security domains identified in 5G-ENSURE remains applicable for Industry 4.0 vertical domain:

- Trust builder
- AAA cluster
- Security monitoring cluster
- Network management & Virtualization isolation

But new objectives like resiliency and high availability need to be covered.

7.2.4 5G Architecture

The deployed testbed shall reflect what a 5G network could be, in accordance with ETSI's NFV reference architecture.

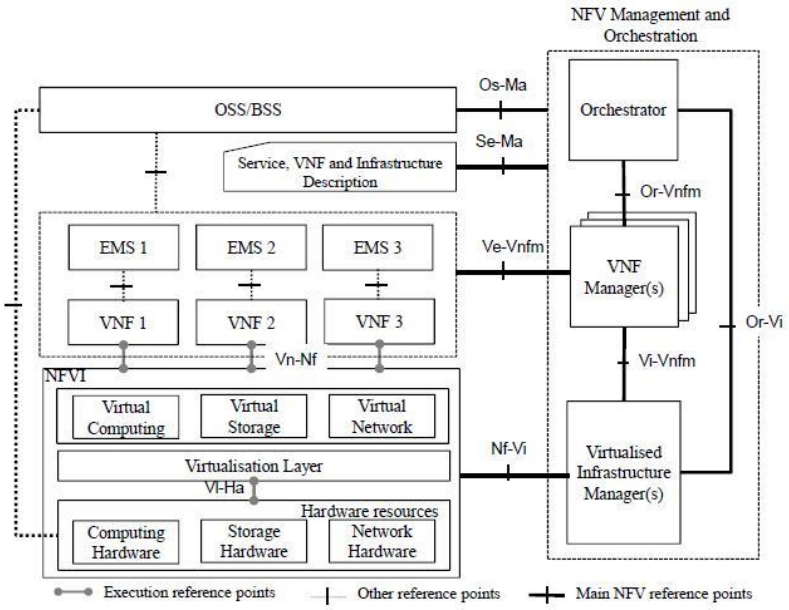

Figure 19: ETSI NFV reference model

Some building blocks shall be selected in a list of carrier grade and state-of-the-art open source solutions and may follow OP-NFV recommendations (refer [22]):

- Operating Systems: Linux (Ubuntu & CentOS)
- Hypervisor: KVM, tuned for VNFs support
- Virtual Infrastructure Manager: OpenStack
- SDN Controller: OpenDayLight, ONOS
- VNF Orchestrator: Open Source MANO

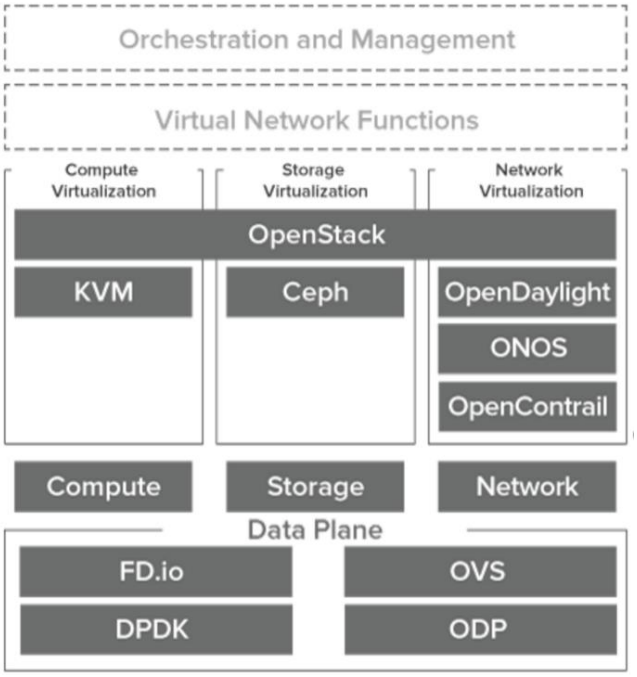

Figure 20: OP-NFV technical overview

This is very much in line with the recommendation of 5G-PPP Phase I SONATA project (refer to [23]) and the extension of the testbed should benefit from the SONATA contributions to key communities like OPNFV, OpenDayLight, OpenStack and ETSI's NFV ISG, which are the pillars of the extension plan proposal.

8 Conclusion

As a conclusion, 5G-ENSURE project provides a business canvas that depicts the recommendations for operating a testbed on 5G security. This approach will be applied by b<>com in order to further develop testbed activities in view of requirements coming from Phase II projects.

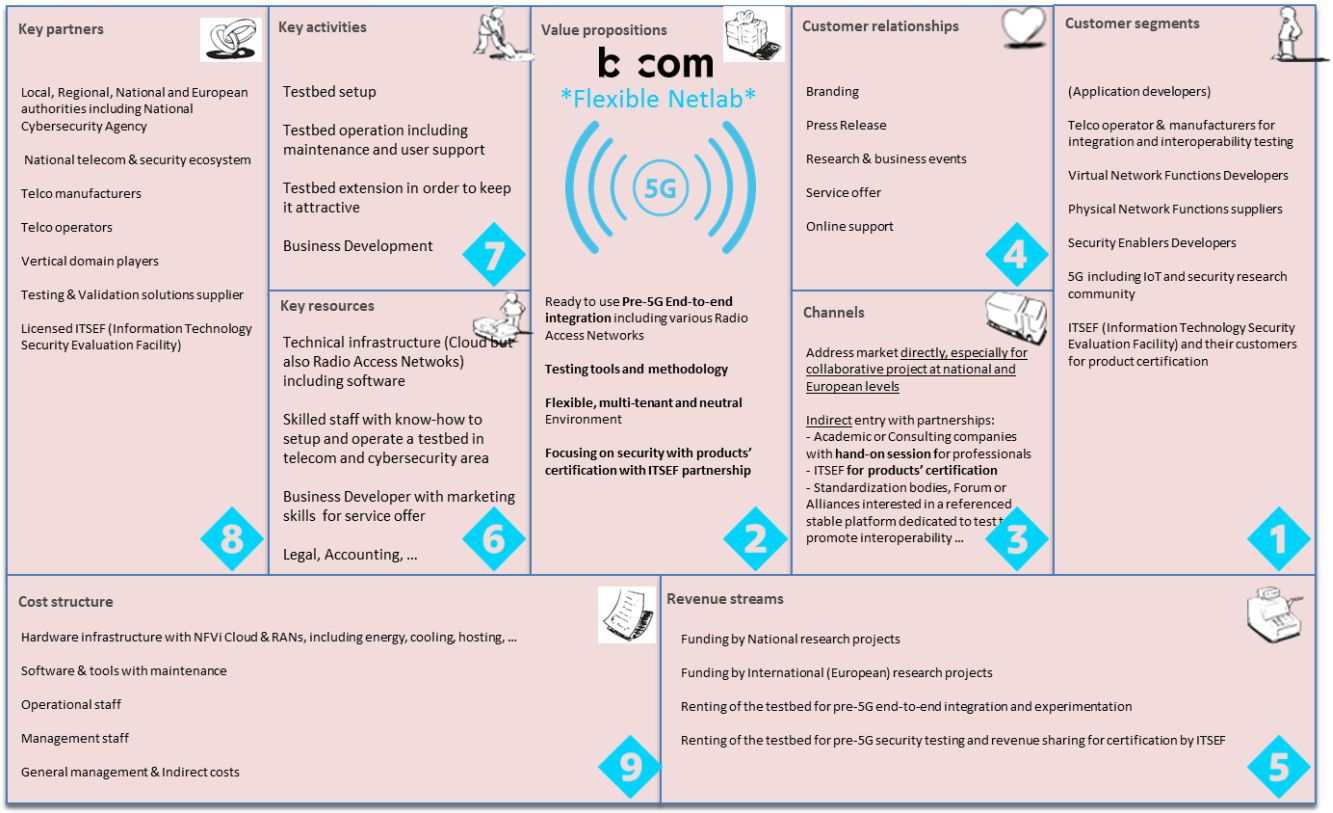

Figure 21: b<>com * Flexible Netlab * Business Canvas

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A Testbed user satisfaction survey

A.1 Questionnaire

User Name:

Company name:

Position in company:

- Project Management ☐
- Senior Architect / Expert ☐
- Senior Development Engineer ☐
- Development Engineer ☐
- Other: ☐

Company profile:

- Research Institute ☐
- Telecom Service Operator ☐
- Telecom Infrastructure Manufacturer ☐
- Other: ☐

Before 5G-ENSURE

- What did you think about testbed before 5G-ENSURE project?
  - Useful ☐ Useless ☐
  - Why? (please elaborate)

- More generally, what did you think about testbed in Research & Innovation H2020 project?
  - Useful ☐ Useless ☐
  - Why? (please elaborate)

During 5G-ENSURE project, did you use 5G-ENSURE testbed? Yes ☐ No ☐

- If Yes

1: Highly Dissatisfied	2: Somewhat Dissatisfied	3: Neutral	4: Satisfied	5: Very Satisfied
		①②③④		

  - Remote connection experience? ☐ ☐ ☐ ☐ ☐
  - Helpdesk to submit request(s)? ☐ ☐ ☐ ☐ ☐
  - Operation Staff skills (to understand your request(s) and provide a solution)? ☐ ☐ ☐ ☐ ☐
  - Time by Operation staff to answer your request(s)? ☐ ☐ ☐ ☐ ☐
  - Testbed infrastructure resources types (CPU, Storage, Network)? ☐ ☐ ☐ ☐ ☐
  - Testbed infrastructure resources availability? ☐ ☐ ☐ ☐ ☐
  - Testbed nodes interconnection ☐ ☐ ☐ ☐ ☐
  - Testbed workflow for enablers' deployment and evaluation? ☐ ☐ ☐ ☐ ☐
  - Testbed tooling (packaging, Artifactory, Test Link, …)? ☐ ☐ ☐ ☐ ☐
  - Testbed usability? ☐ ☐ ☐ ☐ ☐
  - ROI (Return on Investment) for using a testbed for enabler owners! ☐ ☐ ☐ ☐ ☐
  - What needs to be enhanced or added in 5G-ENSURE testbed? (please elaborate)

- If No, please explain why:
