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EMPOWER White Paper

Empowering Transatlantic Platforms for Advance Wireless Research

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Introduction

Digital transformation is at the heart of our society in all the activities we develop. This evolution is made possible by the progressive deployment of a sophisticated service infrastructure characterized by its size, diversity and articulation with the various players. The result is a system of systems whose availability, reliability, security and performance challenge its design in order to make it a strong asset of sovereignty, innovation and industrial competitiveness ideally to serve the well-being of the citizens.

It is well recognized, as a best practice in many scientific disciplines that thought experiments can contribute to the discovery process. This is illustrated for example in high-energy physics by the Einstein/Bohr and their Photon Box seeking for a kind of experiment that Schrödinger considered impossible to realize. It is unfortunate that for years, it was believed by several stakeholders that in order to research computer science and electrical engineering, commercial infrastructures (like Amazon EC) were sufficiently good. However, a thought experiment assumes a full control of the environment together with the ability to reproduce the results observed.

Fortunately, experimentally driven research in digital infrastructures has developed in order to equip the relevant communities with instruments that can assist them with testing various design assumptions and deployment scenarios. Testbed as a Service (TaaS) appeared to bridge this gap and propose now matured solutions for that purpose. OneLab/FIT[1], GENI[2] and Fed4Fire+[3], are examples of such solutions that have hosted thousands of experiments and hundreds of users. They are now extended and enriched through new worldwide initiatives such as SLICES[4], NSF/PAWR[5], CENI[6] and ICT-17[7].

Based on the experience accumulated over the last decade, the community is currently exploring the design characteristics of the next generation advanced test platforms. Following the foundation principles, an open-source approach is pursued, trying to embed the emerging design paradigm of digital infrastructures such as virtualization, containers, cloud, DevOps, microservices in order to ease the entire life cycle from design to operation. In addition, important industrial initiatives addressing a similar test objective, such as ONAP[8], O-RAN[9], OMEC[10], TIP[11] and OAI[12] are considered and monitored.

[1] https://onelab.eu/
[2] https://www.geni.net/
[3] https://www.fed4fire.eu/
[4] European initiative to build an ESFRI projects
[5] https://advancedwireless.org/
[6] Chinese Experimental Network Initiative
[7] https://5g-ppp.eu/5g-ppp-phase-3-projects/
[8] https://www.onap.org/
[9] https://www.o-ran.org/
[10] https://www.opennetworking.org/omec/
[11] https://telecominfraproject.com/
[12] https://www.openairinterface.org/

This is a very challenging objective as the target is really broad, covering access, edge and core technologies, wired and wireless.

This white paper suggests some objectives and potential targets that the EU/US community could address jointly in order to provide efficient, scalable, simple and sustainable test platforms to the community.

1. Digital infrastructures and scientific challenges

Digital infrastructures are the outcome of several decades of evolution of both the telecommunication and computer software industry. An important transformation is happening, powered by technology and driven by applications. Following the rise of the Internet and the wireless push, this transformation shows a fantastic disruptive capability. It is associated to the IoT and cloud evolution as well as to the emergence of the so-called verticals. It develops on the virtualization techniques and on the "softwarization" of the network functions, enabling the ability to program the infrastructure, capturing the "on-demand" user's need and therefore providing more agile resource provisioning.

The historic separation between the network and the compute has vanished. As defined by Sun microsystems long ago, "the Network is the Computer" (John Gage 1984); resources are everywhere supported by virtualization, distribution and cloud SaaS.

This is the motivation for developing a holistic approach where all resources (compute, storage, network) are associated to continuously design, operate and automate the full life cycle management of applications and services.

The architecture guidelines are articulated around three key principles:

- *Cloud*: as to obtain statistical gain and manage the set of resources in a dynamic manner;
- *Software*: to support the agility related to the on-demand evolution, exploiting the commoditization of most of the hardware components;
- *Edge*: as a solution for mission critical services and a complement to the cloud.

The technology serves the mission of the above principles, involving IoT, wireless, optical and the cloud to name a few. The rapid evolution from wired to wireless communications has been supported by the constant enhancement of the latter; contemporary wireless protocols are capable of transmitting multiple Gbps over the air, thus revolutionizing both communications and services being offered. In the recent years, industry has been pushing towards the creation, standardization and subsequent small-scale trial deployment of the 5th Generation of mobile network access (5G). 5G in its full deployment is expected to fully transform the current infrastructures landscape by meeting several stiff performance requirements. These requirements enable through the introduction of new air interfaces (5G New Radio – 5G NR)

and the development of a new and optimized Core, the operation of multiple new aspects for communication, such as Ultra Reliable Low Latency Communication (uRLLC), enhanced Mobile Broadband (eMBB) and massive Machine Type Communications (mMTC), leveraging both higher network capacity (orders of multiple Gbps) and significantly lower end-to-end latency (less than 10ms end-to-end compared to 100's of ms today).

Towards supporting these new services offered over the network, progress need to be made in computational resources as well. Massive deployments of sensing devices, along with intercommunication protocols with fixed infrastructure, and new services aiming at enhancing citizens' life constitute a very complex system that generates large amounts of data needed to be processed in real time. Therefore, data center resources should be deployed closer to the edge of the network, in order to allow Ultra-reliable low latency communications (URLLC) from the Radio Access Network (RAN) to the data center nodes (DC). In addition, new proposals extending the Edge towards the end-user, harvesting the available computing power at the terminals are emerging as mechanisms to further reduce the latency of communications. This new concept of Edge, including MEC solutions hosting distributed data analytics together with Machine Learning algorithms will emerge as key architectural innovations.

The call for a new generation of test platforms is justified by the emergence of 5G and beyond infrastructures that require adapted and well-tailored tools for testing and developing trust and confidence regarding the deployment phase. The requirements for these new platforms are made more complex because two different targets are considered simultaneously. On the one hand, they should address the demand from specific communities to experiment with innovative design (for example advanced wireless such as mm-wave, massive MIMO, etc.). On the other hand, the so-called verticals (or key application domains) start to be deployed and various assumptions have to be carefully assessed using relevant platforms. The later requires that the underlying platforms are stable and provide a service good enough to run these applications. Therefore, Test platforms should be able to address the end-to-end scenario, integrating all technologies and components.

Building blocks for testbeds will be equally important as related scientific challenges are numerous, focusing on specific emerging technologies and protocols for IoT, wireless, cloud or services to much broader challenges addressing new verticals such as healthcare, automotive, industry, agriculture, etc.:

- New waveforms;
- Higher frequencies up to THz;
- Generation of data to train algorithms;
- AI applied to wireless protocols at all layers;
- Distribution of intelligence into the Edge of the network;
- Power consumption and energy efficiency;
- Integrated sensing and communication;

- Integrated terrestrial and non-terrestrial networks;
- Security and privacy;
- New security issues and challenges that arise from the verticals and the ubiquitous network;
- Seamless user experiences across technologies and domains;
- Interoperability and security in verticals.

2. The need for a scientific instrument and the community to serve

Digital communication and computer infrastructures are the most complex and largest system created by mankind. The scaling factor can be expressed in terms of number of end-users, number of connected devices, number of flows or number of applications to manage, which highly exceed the numbers of any other human-made system. Such a complexity makes very hard the experimentation of isolated parts of this system, requiring complex interactions with the rest of the sub-elements. As a consequence, components and systems should be extensively analysed and tested in integrated infrastructures where the effect of a specific modification can be evaluated in the presence of the remaining components of the network. The testing should be organized and conducted following the best practices in testing and performance evaluation, namely the test should be developed under a fully-controllable environment and they must be reproducible. Due to unforeseen effects that an experiment may produce in the network, commercial infrastructures cannot be used in most cases, as no control is proposed, it is the fact that a commercial infrastructure is not open enough and flexible enough for addition from and experimentation by third parties.

As a consequence, there is a clear need to research and develop scalable, robust and secured digital infrastructures. Scientific instruments are key enablers to support their design and execution phases.

This instrument is of utmost interest to a large community. They are primarily the scientists that have contributed to the development of the Internet, now being extended to the compute and distributed system communities. These communities are well identified with respect to various scientific societies like the IEEE or the ACM. For instance, the IEEE ComSoc and CompSoc chapters sum to about 29000 members in Europe and 131000 worldwide. The equivalent ACM chapters (Sigcomm, Sigmm) is worth 4000 members worldwide. The relevant scientific conferences and journals are mostly supported by IEEE and ACM such as ICC, Globecom, INFOCOM, Mobicom, WoWMoM, ToN, ToMC, ToC, Sigcomm, Conext, etc. They all contribute to the development of the knowledge in this rapidly developing domain as well as to their design and standardization.

3. Past and present, lessons learned

Test platforms, as a support to the design of networking technologies and architectures, have been developed and operated for decades. PlanetLab[13] was established in 2003 as an internet overlay, using virtualization as a mean to support concurrent experiments in Internet like environments. It was then federated with PlanetLab Europe[14], providing remote access to more than 1000 virtualized router-like systems to experiment with networking, distributed systems, algorithms and protocols. Originally funded by NSF and Intel, operated by Princeton University and Sorbonne University (for the European part), it is still providing a service today and is cited in more than 16.000 publications that have used PlanetLab to support their evaluation. Another successful but different test platform is ORBIT[15] (Open-Access Research Testbed for Next-Generation Wireless Networks). It was first deployed to provide large-scale access to programmable wireless components in order to specifically support the research in advanced wireless technologies and protocols. ORBIT shows more than 25000 publications in Google Scholar. Global initiatives towards ICT test platforms have developed over the years in order to mobilize the international community and propose common de facto standards for the basic components of the facilities. Two parallel and articulated initiatives were instrumental in establishing the foundation for these test platforms, namely NSF-GENI in the US and the DG Connect-FIRE in Europe. GENI was active from 2008 to 2016 with a cumulated budget of about 120M$ to which can be added other calls such as NSF CloudLab[16] and Chameleon[17] (2013-2018/20M$). Similarly, EU FIRE started in 2007 and will continue until 2020 with a global funding from the EC of roughly 200M€.

We observe that these platforms have fulfilled an important need for the associated research communities (networking with PlanetLab, wireless with Orbit, Cloud with CloudLab, etc.). They were instrumental to better understand the need, identify the important components, propose a reference architecture and APIs (at different levels), qualify the experimenter's experience, discuss the sustainability. It will positively influence the methodology to be followed for preparing the next phase.

The future generation of platforms already started with three different initiatives:

- USA PAWR (Platforms for Advanced Wireless Research): NSF + Industry, 2017-2022, 100M$;
- China CENI (Chinese Experimental National Infrastructure): 2018-2022: 190 M€;
- EU ICT 17/19: 2019-2022: 150 M€ (60M€ for ICT-17 and 90M€ for ICT19).

[13] https://www.planet-lab.org/
[14] https://www.planet-lab.eu/
[15] http://www.winlab.rutgers.edu/projects/Orbit.html
[16] https://www.cloudlab.us/
[17] https://www.chameleoncloud.org/

4. Mission and design principles

"Research Infrastructures are facilities, resources and services that are used by the research communities to conduct research and foster innovation in their fields"[18].

The mission of the initiatives cited above, though different in their approaches, is to provide the research and engineering community with a fully controllable, programmable virtualized digital infrastructure test platform. It aims to answer the fundamental questions regarding digital infrastructures in an evolving environment, enable new technologies to support ICT breakthrough discoveries with the use of both OTS and adhoc programmable technologies together with advanced design and execution cloud-based solutions.

They should act as a catalyst to enable and foster the data-driven science and scientific data-sharing in this area. Open research data should be considered together with the test platform and ultimately contribute to the deployment of a data repository where all data produced by the platform, under some policies, could be made available under the FAIR principle (Findable, Accessible, Interoperable, and Reusable) and initiatives such as EOSC[19] (European Open Science Cloud) in Europe.

Benefits and objectives towards the experimenters, coming from the research and engineering communities

- Equip researchers and practitioners with a wide range of scientific and experimental resources and tools by deploying and operating a large-scale platform providing access to cutting-edge technologies in wireless and wired networking, IoT, Cloud as well as end-to-end;
- Offer a wide variety of advanced computing and networking resources in order to respond to the needs of future dynamic and highly software-based systems;
- Provide advanced test tools to ensure reproducibility through an automated data repository and support an open data approach for these communities. A certification solution can be considered alike Cascad[20] that warrants that the numerical results (tables and figures) reported in a scientific publication (working paper, published article, and report) are reproducible;
- Build the capacity by strongly contributing to the important education effort targeting both students and engineers, also boosting brain circulation of early career scientists and trainees.

Empower aims to play a catalyst and coordination role regarding Digital Research Infrastructures in the domain of advance research platform, 5G and beyond:

[18] https://www.esfri.eu/esfri-roadmap-2021
[19] https://www.eosc-portal.eu/
[20] https://www.cascad.tech

- Engaging the scientific community primarily centered on digital sciences and the research domains involved in the design of large-scale digital infrastructures. It includes, but is not limited to, distributed systems, networking, wireless research, interoperability/testing, embedded systems, software engineering, system management, security, reliability, etc.;
- Propose a coherent vision and roadmap to policy-makers in research infrastructures in Europe and the USA;
- Federate research communities working on these subjects from software and computer system architects to transversal (vertical) applications. Articulate with other important relevant initiatives (O-RAN, OMEC, etc...);
- Facilitate bi-(multi) lateral initiatives leading to a better use and development of research infrastructures in this area;
- Involve stakeholders from supply side to demand side, enabling the testing of new technologies but also accelerating the deployment of transformative services.

5. EMPOWER mission

EMPOWER ambitions to articulate and coordinate the activities related to advanced wireless platforms conducted in the US and in Europe. It will build on the existing infrastructure but also explore how we can push the envelope of the future platforms to provide advanced solutions, more flexibly and efficiently.

EMPOWER was kicked-off on November 1st 2018. Liaison with NSF PAWR was already operational. Activities were developed and deployed according to plan. In particular, a first workshop was jointly organized by EMPOWER-PAWR, co-located with IEEE Infocom 2019 in Paris on 29 April 2019. A second workshop was held within the EUCNC 2019 conference in Valencia, on 18 June 2019. Minutes of both workshops' outcome have been published[21].

As a first step, the main objective of these joint workshops was to organize the dialogue between the three ICT-17-2018 projects and their NSF PAWR counterpart. It was also extended to the ICT-19-2018 projects dealing with the verticals.

EMPOWER is acting as the catalyst for such collaboration and employing different tools to foster joint activities, such as organization of joint workshops, mobility of researchers, hackathons, etc. Main issues to be further discussed include: (1) sharing practices and solutions, (2) Exploring E2E system level, (3) The EMPOWER roadmap, (4) Data management and Reproducibility. Key to EMPOWER is to orchestrate and support the cross-Atlantic collaboration, and one target is to foster mutualization of software development and computing/networking resources. With the aim to share tools and results, EMPOWER will

[21] https://www.advancedwireless.eu/

explore coordinated deployments and PoC demos, as well as the creation of an evaluation activity.

A central topic of discussion has been the usage of Open Source platforms for experimentation, production and infrastructures:

- Radio platforms: use of OAI/O-RAN or other platforms for the developing of the RAN in an open reference platform;
- Core platforms: possible use of ONF/OMEC or other platforms for the development of the Core part of the open reference platform;
- The need of an open NFV framework to provide a relevant test framework and toolset to perform tests.

A key aspect is the use of open platforms for academic research and push ideas towards the industry for building industry-lead PoCs and research. The potential to use ICT-17/19/20 and the evolutions in Horizon Europe and PAWR nodes in order to bring forward the joint research and ideas via industry driven initiatives. Additional issues discussed include: (1) how to foster mutualisation of software development and computing/networking resources. One way is to lead to ***common reference designs*** between EU/USA teams (academia and industry); (2) how to coordinate proof-of-concept joint demonstrations at high-profile venues bringing together teams from EU and USA platforms. A solution is to ***promote joint experimentation on multiple platforms***; (3) how to create of an evaluation activity for collecting and disseminating results and one answer is to generate joint scientific dissemination.

6. Methodology

During the first year of the EMPOWER project the activities have been focused on the analysis of current approaches towards building the advance wireless infrastructures for research. Through several workshops involving the different stakeholders, a common view on the requirements of an infrastructure that may be used to develop the next generation of wireless innovations have been discussed. Following this on-going discussion, EMPOWER and PAWR are organising a set of site visits for key researchers in the area. The aim of these visits is to give a first-hand view of the different approaches considered in Europe and USA, understanding the strong and weak points of the different strategies followed by the different sites. The visits will consider all the experimental facilities discussed in the 5G-PPP Trials WG, with a starting point on the 5G-PPP Experimental Facilities Cartography.

The planned visits will be bi-lateral, a delegation from PAWR and NSF will come to Europe to meet the selected facilities and discuss experimentation with some of the scientists running them. In the same way, European scientists will travel to USA to meet the PAWR facilities.

Activities will continue to developed and be monitored in order to address the EMPOWER mission:

- Analyze the landscape of RI in Europe and US;
- Identify the gaps in Digital Infrastructure RI ecosystems;
- Emphasize the scientific challenges;
- Consider Open data and reproducibility;
- Formalize the Access policy (FAIR principles);
- Study the Socio-economic impact and sustainability.

7. Conclusion

EMPOWER's mission is to mobilize the various Forum dealing with Research Infrastructures addressing future Internet, communication and services. It aims to provide strategic guidance but should also be very practical, providing tools to support a tight collaboration at all levels of the various communities and initiatives. This framework is open and welcome all those who would like to contribute. Ultimately, it ambitions to help understanding how to transform current generations of test platforms and provide guideline about a common reference design.