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EMPOWER White Paper

Future trends analysis for Advance Wireless Platforms

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Contact:	https://www.advancedwireless.eu/#contact

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Introduction

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, wireless and cloud/HPC evolution as well as to the emergence of the so-called verticals or application domains. It develops exploiting the virtualization techniques and software-enabled network functions, providing the ability to program the infrastructure, capturing the "on-demand" user's need and therefore allowing 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. The same vision is reported by Nick McKeown in a recent talk ""***We will think of a network as a programmable platform*** … We will no longer think in terms of protocols. Instead, we will think in terms of software. This trend is going to impact the all telecommunication and computer-based sector, from design to products and operation. This will disqualify the multi-year planification approach based on new generations (2G/3G/4G/5G, etc.) and threat the corresponding industry.

It is well recognised, as a best practice in many scientific disciplines that ***thought experiments*** can contribute to the discovery process. 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 for the ***future of the Internet***. EMPOWER ambitions to accelerate the joint development between the EU and the US on advanced wireless platforms targeting the new connectivity frontiers beyond 5G. EMPOWER targets the creation of a joint EU-US advanced wireless ecosystem for (i) bridging the relevant EU-US Wireless communities and stakeholders, such as scientific researchers, platform engineers, standardization experts, regulators, and product incubators; and (ii) developing a strategic EU-US collaboration agenda and supporting its execution ahead of worldwide competition for beyond 5G connectivity standards. Moreover, through these EMPOWER instruments, we aim to create an efficient means for stimulating the circulation of ideas and people between European and similar American experimental wireless platform initiatives.

In parallel to the definition of the overall strategy, the partners have been working on the demand, namely, the analysis of the trends, status and plans for advanced wireless that helped to define the first technology roadmap for advanced wireless. This roadmap was the basis for the consultation on the baseline 5G evolution technology roadmap from EMPOWER project. The aim of this consultation was to gather inputs from the community to create and update the advanced wireless technology roadmap based on the analysis of trends for B5G in the respective research, standards, and spectrum communities, in the EU, the US, and globally. Moreover, activities related to the transatlantic deployment and evaluation methodologies started with the publication of a first report on joint technology demonstrations and data analysis, completed by a survey of software tools and computing architectures for advanced wireless platforms. The objective here is clearly to structure the future solutions that will be integrated in the test platforms. It targets software components (control and experimental plane), API, management and operation of the platform, the Data Management Plan and reproducibility.

This white paper focus on important topics addressing both the demand and the need. It first analyse the diving forces and technology trends towards BY5G. Then, it provide a first insight into an expert consultation analysis about the pivotal future wireless technologies. The reference architecture as a support for the interoperability of the future test platform is then introduced followed by future activities and solicitation on 1- reproducibility and 2-AI. Finally, the paper presents some important coordination activities between US and EU teams.

1. Driving forces and technology trends towards beyond-5G

The year 2019 saw the first commercial rollouts of 5G networks in several countries, noticeably in Europe, the USA, South Korea, Japan and China. According to GSMA Intelligence in March 2020, 5G is live in 24 markets and in 2025 it is believed that 5G will account for 20% of global connections.

Spectrum auctions have been carried out, infrastructure equipment have been supplied, 5G devices have been shipping, and operators have started to offer 5G subscription plans to the end users primarily for super-fast broadband services. In the light of this 5G commercial fever, the global wireless research and development (R&D) communities have started actively to lay out their agendas for what is coming up next beyond 5G (B5G). These agendas varied in time scales in line with the inherently different time horizons of the various wireless R&D communities, ranging from longer term agendas targeting 6G as set out by the more visionary research forums, down to shorter term agendas targeting the next immediate enhancement of current 5G specifications as set out by the more conservative standardization organizations.

Wireless communication is one of the largest growing industries globally. The wireless data rate is doubling every 18 months. The latest Ericsson Mobility Report forecasts 160 EB (Exabytes) global monthly traffic in 2025. A major increase in available data speeds is also foreseen. The latest Cisco Annual Internet Report forecasts that both mobile and Wi-Fi speeds from mobile devices will triple between 2018 and 2023. It is also expected that 5G speeds will be 13x higher than the average mobile connection by 2023.

1.1 Stakeholders and driving forces

To understand the driving forces towards 6G, the EMPOWER project early identified a number of stakeholders. These can be found among three types of groups: Research programmes, Industry and Standards Forum, and Regulating organizations. These three groups represent effectively the academic sector, the industry sector and the public sector, which all have their role and interest for developing new technologies and technological solutions. In the context of EMPOWER, the focus has been on the European and US activities.

The longest perspectives are usually found in the research programmes, where, in Europe, the EC's Horizon2020 (H2020) programme is by far the most influential. The H2020 programme, which is approaching its end, has been quite focused on developing the 5G technology, and putting it to test. Around 25 projects are currently running as part of the 5G PPP Phase 3. The last project calls, however, are opening for B5G perspectives, and some 15, or more projects are expected to be launched addressing different flavors of research beyond 5G, from user perspectives to hard core technology visionary projects.

Some of these late H2020 projects are meant to be the bridge to a larger focus on B5G towards 6G research to be addressed in the next framework programme, Horizon Europe, which is expected to be launched at the end of 2020.

On the US side, the National Science Foundation (NSF) supports fundamental research and education in all the non-medical fields of science and engineering including future wireless systems. On this side, the US-IGNITE NSF PAWR (Platforms for Advanced Wireless Research) programme focusses on platforms for advanced wireless research, including four projects, three already launched from phase 1 and 2, and one additional expected from phase 2. This programme was launched in 2018 and continues until 2024. Also, important drivers are the US DARPA programmes providing massive testbeds for researchers and also the "Spectrum challenge", which aims to drive forward collaborative intelligent radio networks using AI.

Among industry and standards forums, the 3GPP is probably in a most prominent position, because it "owns" the "generation" concept to a large degree. However, there are numerous initiatives adding to their work and maybe challenging the thinking. 3GPP develops the different 'G's, which up to now has been based on a strong network centric paradigm based on the old telephone network model.

Following the release of 3GPP 5G New Radio (NR) Release 15, the 3GPP is now gearing towards finalizing 5G NR Release 16 by Q2'2020. In parallel, there has been a few study items progressing with the aim to become work items for the future Release 17, that is being planned for the year 2020-2021.

The main 'opponent' to the telco-model is probably coming from the internet technologies, more precisely from the IEEE 802 LAN/MAN Committee, in which Working Group 11, standardizing WLAN, often better known as Wi-Fi, is the most prominent. The IEEE 802.11 WG has been actively specifying radio technologies. Whilst 802.11ax and 802.11ay are nearing completion, the 802.11 group continues to work on enhancements that push the performance envelope to new highs, such as the work underway in 802.11be targeting much higher throughput compared to 802.11ax.

In addition, as the new use cases including many in local area networks demand additional capabilities to conventional throughput and latency, such as positioning and very low power, IEEE 802.11 has been working in parallel to improve additional capabilities such as positioning features, wake-up radio, light communications and enhanced broadcast services. In addition, a new area of work has recently arisen, IEEE 802.11 based sensing.

Other industry groups are organizing the operators, like GSMA and NGMN, which work for developing the complete ecosystems for technologies and establishing clear functionality and performance targets as well as fundamental requirements for deployment scenarios and network operations.

Finally, the public sector's interests are twofold: First to promote technological solutions for the benefits of society, and second, to regulate for fair usage and competition. In the EMPOWER context, we have mostly been looking into the spectrum issue, because access to frequency resources are crucial for providing services. Even technologies are developed to improve the spectrum efficiency and utilization, one of the largest leaps in e.g. capacity performance for 5G comes from the fact that more spectrum is made available. Globally, ITU-R decides the overall allocations, while regional and national regulators provide practical means of utilizing them. In 2019, the World Radio Conference allocated 17.25 GHz more spectrum for 5G in the upper bands from 24 to 71 GHz. This is also important spectrum for 6G.

Two major trends are also seen for more efficient spectrum usage. Unlicensed spectrum has been 'reserved' typically for WLAN and other short-range technologies, but now we also see that this is being addressed for cellular use. The other trend has been long going on, and that is improved sharing mechanisms. This came to attention a few years ago, when 'cognitive radio' was promoted as putting an end to conventional licensing. This did not take off, but a lot of the knowledge and technologies developed will be utilized. Already multi-tier licensing is being tried out in some markets, and with the use of AI techniques, dynamic spectrum sharing will be important for 6G.

1.2 Wireless technology trends towards 6G

In addition to, and partly based on, identifying the main stakeholders and drivers above, EMPOWER has identified some important technological trends for enablers towards 6G.

As mentioned above, one of the important enablers for massive improvements in throughput and capacity is the availability of more spectrum. Therefore, an increasing activity is seen on extreme high frequencies above 100 GHz, often denoted sub-THz and THz spectrum. Over the next decade, it is believed that advances in devices, circuits, software, signal processing, and systems will make sub-THz and THz communications a commercial reality. Beyond communications, these frequencies offer additional capabilities such as sensing, radar, imaging, and ultra-accurate positioning, which is promising a new paradigm of integrated sensing and communication in the same frequency bands. The FCC in the US recently announced in 2019 giving Spectrum Horizon experimental licenses for spectrum between 95 GHz and 3 THz, which makes a total of 21.2 GHz of spectrum between 116 and 246 GHz available for unlicensed devices.

Metamaterials (meta- from Greek meaning "after" or "beyond") is believed to play a role in future wireless applications. Metamaterials are synthetic composites with structures and properties not found in natural materials. In wireless communications, metamaterials are envisioned for the design of new classes of antenna arrays called meta-surfaces bringing the capability to shape the radio waves according to the generalized Snell's laws of reflection and refraction. It is also foreseen that these materials can be embedded into the environment as "Intelligent Reflecting Surfaces" (IRS), to change the characteristics of the wireless environment, and optimize its operations accordingly.

Since May 2019, SpaceX' system 'Starlink' has launched more than 300 satellites, planning for almost 12000 before 2027, and it is anticipated that the cost of building and launching LEO satellites will decrease significantly.

Further advances in manufacturing, robotics, energy, and artificial intelligence will significantly enhance their capabilities. LEO satellites are therefore envisioned to be massively deployed over the next decade making them a co-primary infrastructure to consider from the outset in the design of 6G. Further, High-Altitude Platforms (HAPs) are designed to fill in the gaps between LEO satellites and ground base stations. They include passive balloons and highly advanced drones with wingspans larger than 20 meters. HAPs are anticipated to be deployed more widely and in higher density and enhanced by advances in manufacturing, drones, energy, and artificial intelligence.

Artificial Intelligence (AI) is widely tipped to be a major disrupting technology that will impact the design of beyond 5G and 6G. AI has already been successfully applied in wireless communications, from physical layer design to radio resource management and mobility management, and to network management and orchestration. Federated learning and transfer learning being two important machine learning approaches that makes this possible. In addition to the big data-driven centralized approach today, we will see more of a small data-driven distributed approach in 6G. The AI services will be ubiquitous, from the core to the end devices in the network. To satisfy increasingly stricter latency requirements, more intelligence will be pushed towards the edge of the networks.

Quantum communication is envisioned as a disrupting technology that will help 6G (and beyond) achieve its targets of Tbps throughput, ultra-low latency and ultra-high security. Initial quantum devices have been realized recently using single photon emitters operating at few degrees above the absolute zero temperature. A complete quantum computing architecture has recently been demonstrated. The next decade is promising significant advancements to quantum devices so they can operate at normal temperatures.

Cell-free massive MIMO networks, also denoted network MIMO and distributed MIMO, makes the network more user-centric, meaning that each user is connected to a user specific subset of Access Points (APs) that cooperate to jointly serve the user. The network appears to be without any cell boundaries during data downlink transmissions, at least from a user perspective. Theoretical studies have shown that cell-free massive MIMO networks can achieve significantly better performance than conventional small cell networks.

2. Expert Consultation Analysis

In the context of its mission to advance wireless research beyond 5G in Europe, the USA, and globally, EMPOWER has recently issued a baseline technology roadmap on 5G evolution in the timeframe 2020-2030 [1]. The roadmap scope is set on wireless technology advances that are pertinent to the evolution of 5G new radio (NR) over the next decade 2020-2030. Figure 1 below illustrates the evolution of cellular technology and highlights the focus of EMPOWER's baseline roadmap on 5G evolution (IMT-2020) towards 6G (IMT-2030) from the perspective of the radio interface. Such an evolution is driven by an expansion of the verticals targeted and a pervasiveness of intelligence everywhere into the system design.

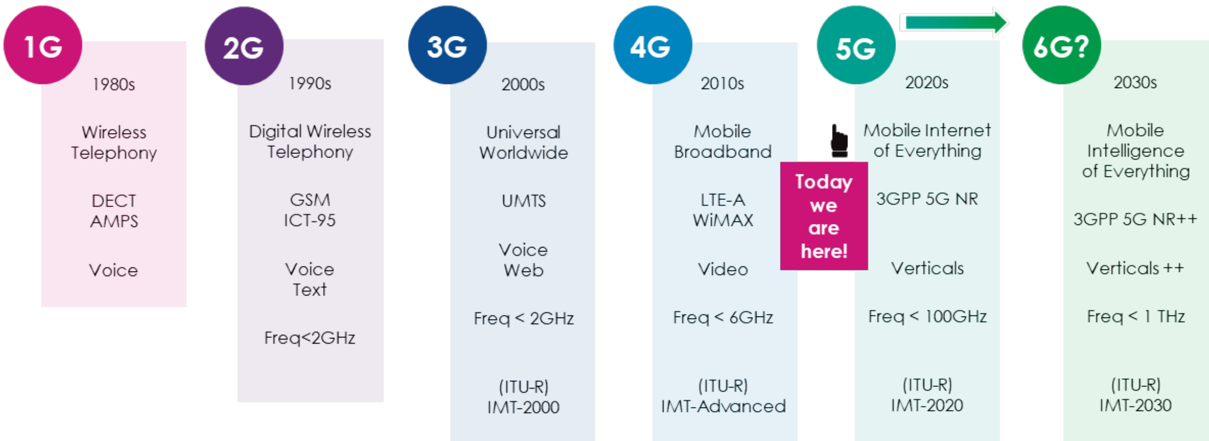

Figure 1: EMPOWER Roadmap Scope.

The EMPOWER roadmap focused on technical trends driving the evolution of 5G mainly in terms of (i) new requirements and therefore new target Key Performance Indicators (KPIs); and (ii) technological advances and new emerging technology. These trends were classified into short, medium, and long -term evolution of 5G depending on their maturity timelines.

First, with focus on the KPIs, EMPOWER presented forecasts on the evolution of 5G KPIs in the short (SEVO), medium (MEVO) and long (LEVO) terms. These forecasts are summarized in the form of trends below:

- Spectrum with leap jumps above 100 GHz all the way up to THz
- Single channel bandwidth expansion from 400 MHz today up to 10 GHz
- Peak data rate moving to a few 100s of Gbps
- User data rate scaling up to a few Gbps
- Connections density doubling to 2 devices per sqm
- Reliability gradually increasing to reach highs of up to 9 nines
- U-plane latency down to a fraction of a millisecond
- Energy efficiency (network and terminal) improving towards 100% gains compared to the values obtained with 5G system as of 3GPP Release 16
- Positioning accuracy improving to a few centimeters
- Mobility support increasing to up to 1000 km/h speed

Second, with focus on the technology, the key technology trends for the short (SEVO) and medium (MEVO)-terms evolution of 5G were derived primarily from the studies around future wireless standards, noticeably 3GPP (Rel-17, Rel-18 and beyond), and IEEE 802 (evolution of 802.11 and 802.15). In both 3GPP and IEEE 802, there is a common trend to put priority on enhancing the various KPIs, such as coverage, throughput, latency, reliability, energy efficiency and positioning, to extend the support towards more emerging use cases, such as (i) V2X, (ii) KPI-demanding industrial IoT, (iii) private networks and (iv) aerial and satellite networks. Furthermore, there is a trend to enhance the data collection and exposure from the network and devices to enable data-driven system optimization through artificial intelligence (AI) technologies. For the longer-term evolution (LEVO) of 5G, the trends are steered towards disruptive technologies, the maturity of which is difficult to predict at present. At the macroscopic level, these trends include (i) the design of disruptive radio transceivers supporting extreme requirements, such as Tbps data rates, sub-ms latency and sub-mWatts power; and (ii) the integration of various wireless sub-systems together, such as licensed and unlicensed, terrestrial and non-terrestrial, communication and non-communication (sensing, radar, imaging). All this is envisioned with pervasive artificial intelligence everywhere in the wireless system design and operation.

Following on the release of the baseline roadmap, EMPOWER launched an expert consultation [2] with the aim to collect the wireless experts' feedback and fine tune the baseline roadmap accordingly. The consultation opened in February 2020 and run for two months until end of March 2020. The consultation was presented in the form of a questionnaire survey spanning four main areas as follows i) KPIs evolution; ii) Technology trends; iii) Experimental challenges; and iv) Roadmap refinement. A total of 26 questions were put forward to the wireless experts for feedback and inputs. A total of nearly 70 experts shared their feedback with a rough split of the demographic between universities and research institutes (60%), and the industry (40%). The respondents were from various countries across Europe, but also North America (USA, Canada) and South East Asia (China, Taiwan, South Korea). The full results of the consultation will be subject for a future publication. In this white paper, we only provide a snapshot of the results with focus on the KPIs trends and wireless technology trends.

First on the KPI trends, the consultation has helped in validating and refining the EMPOWER baseline roadmap. This refinement is presented in Figure 2. Whilst we clearly detect an emerging consensus on the directions of travel and the ultimate KPIs to target in 6G, it is acknowledged that it will however take a few years before the industry converges officially on all target KPIs for IMT2030. This has only recently started at ITU-R with planning for work beyond IMT-2020 discussed at the ITU-R WP5D #35 meeting in February 2020.

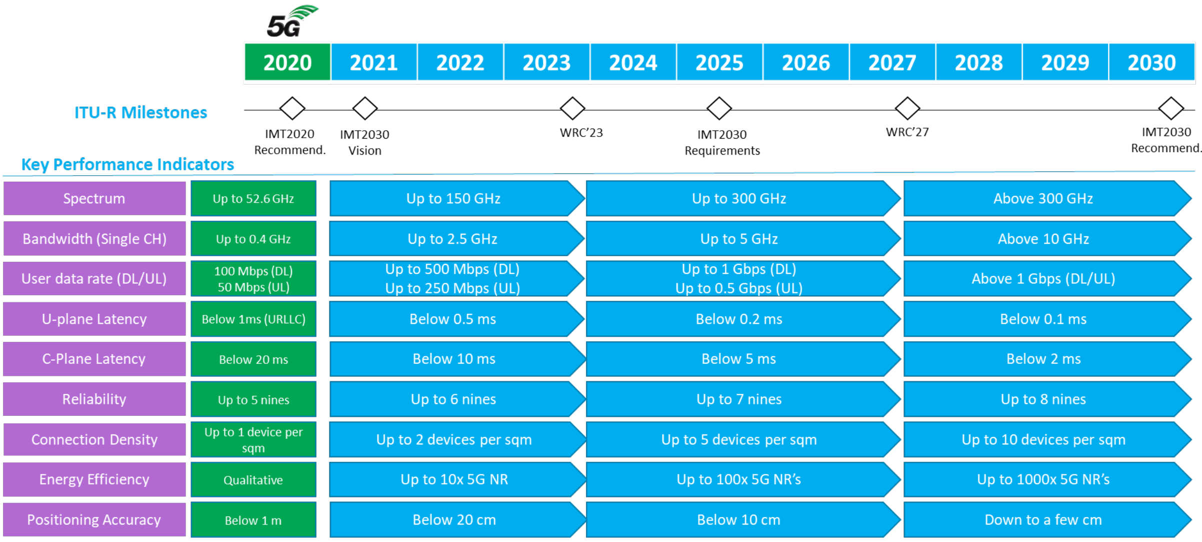

Figure 2: KPIs evolution beyond 5G refined from EMPOWER consultation.

Second on the technology trends, the consultation has helped identifying pivotal wireless technologies for medium to longer term research towards 6G, whilst the shorter term is already defined from ongoing standardization activities noticeably in 3GPP Release 17/18 and IEEE 802. Figure 3 shows the top-10 wireless technologies ranked by popularity from the experts' responses received in the consultation. These technology trends are anticipated to feed into and be further refined at the recently launched ITU-R Report on Future Technology Trends with focus on providing a broad view of future technical aspects of terrestrial IMT systems considering the period up to 2030 and beyond, which will form the basis of the "Vision Beyond IMT-2020".

1. **Wireless AI fusion (18%)**
2. **Sub-THz technology (14%)**
3. **Ultra-low power (12%)**
4. Multi-access (10%)
5. Flying UEs/Nodes (8%)
6. Positioning (7%)
7. Holographic MIMO (7%)
8. IAB (6%)
9. Sensing and Comms (5%)
10. Advanced waveforms (5%)

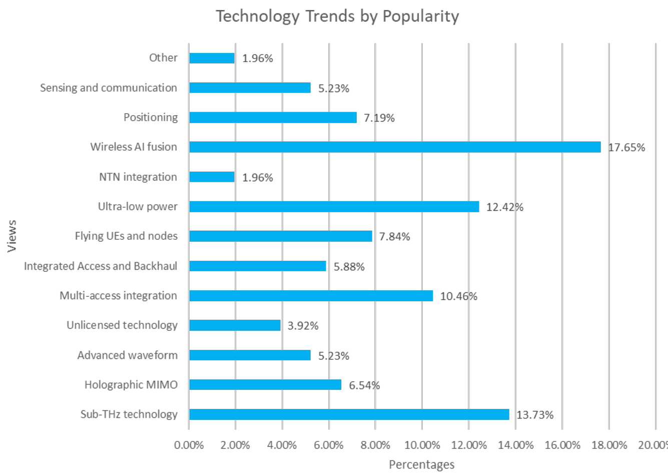

Figure 3: Wireless Technology Tends by Popularity from EMPOWER consultation.

3. Reference Architecture, Reproducibility and AI

In order to offer a scientific instrument for providing experimentation services to researchers who are primarily involved in the design of digital infrastructures, a common reference architecture (RA) is desired. This will serve as a blueprint for site maintainers and guarantee a certain level of homogeneity for distributed experimentation and reproducibility. This should benefit from the wealth of experience gained in EU research initiatives such as FIRE and more recently ICT-17 in addition to those from international initiatives such as PAWR. To this aim, the design of the overall architecture embraces cutting-edge hardware infrastructure, production-grade software solutions – similar to the frameworks used by big industry in Digital Sciences (e.g. Google, Facebook, etc.), and a supporting infrastructure for facilitating the Experimentation as a Service-provisioning paradigm.

The principles are guided by multiple constraints and objectives that manifest themselves in this RA. It is mandatory, at an early stage, to propose a shared level of abstraction that will link the system components in a coherent and efficient way. This is motivated by the fact that the RA should ensure that the system is generic enough to address a large part of the community whilst being specific enough to be suited to focused design objectives of some research communities. These principles are stated concisely as

- Target the research community involved in the design, management and operation of digital infrastructures, enabling a diverse set of experiments that can run concurrently and break the system as isolated from the rest of the experimental infrastructure;
- Support for experiments addressing application domains (verticals such as industrial internet, smart city, connected cars, etc..) but this will likely require a stable and robust underlying infrastructure on top of which the verticals' will be tested;
- Mobilize a large diversity of resources that can support very focused experiments (e.g. design of a new radio protocol from the wireless community) as well as aggregate and assemble diverse resources to support end to end experiments as encountered in the design of a given architecture (RAN, Edge, Vertical)
- Expand easily depending on the evolution of the technology and scientific questions, requiring a means to plug new components to the existing facility;
- Software components should be re-usable in order to ease the reproducibility of experiments as well as to lower the effort to design them.
- The level of abstraction should include the minimum set of components that are necessary to support the experiments synthetic though realistic conditions, whilst avoiding those that are necessary only under real operation (e.g. OAM, billing, etc.).

Although aligning these objectives is challenging, the software-based foundation of digital infrastructures will make it feasible. We expect that it will provide an important asset for sustainability of an experimental facility.

Key technologies that will be used to implement the RA can be organized in hardware components, software components and site deployments. The latter are selected based upon the existing platforms from FIRE, ICT-17, PAWR and similar initiatives in Asia, the experience of a site's local community and the target scientific use cases. Sites should furthermore be selected and configured so that they complement each other in diversity and scale and maximize the overall value of the experimental facility.

1. **Hardware architecture**
   a. *Multiple radio*: for supporting different types of wireless connectivity in licensed/unlicensed spectrum, with existing 5G/4G technologies or their evolution (6G and THz network operation)
   b. *Antennas*: for supporting a wide range of frequency spectrum, as well as beyond existing state-of-the-art applications for Massive MIMO.
   c. *User equipment*: for supporting experimentation with the latest generation of wireless networks (e.g. 5G-NR). Bring-your-own-device (BYOD) cases where experimenters provide their own User Equipment in the facilities is also supported.
   d. *Special purpose processors* (GPU, FPGA, AI-dedicated processors): For facilitating the calculations of computationally intensive tasks. ASIC processors targeting especially Artificial Intelligence/Neural Networks will also be offered.
   e. programmable SDN components with hardware acceleration for user-plane communications (e.g. P4 switches)
   f. *NVRAM memory and in-memory devices*: for complementing the infrastructure and applications running over them with high-speed memory access.
2. **Software Architecture**
   a. *Experiment orchestration components:* for deploying experiments in an easy manner and benefiting from resource virtualization (supporting more users, energy savings).
   b. *Experiment Support components:* for monitoring the status of the entire distributed infrastructure and managing the experiment and relevant data (e.g. visualization, etc.).

c. *Open APIs:* for enabling the extension of the RA with new sites.

3. **Cloud and compute support infrastructure**
    a. This is in order to support functions such as signal processing, controls and related computational, high performance and data intensive computations. Real-time computing considerations are fundamental in this regard;
    b. In addition, it provides the programmability framework for the experimenter, APIs, resource access, reservation and slicing, data storage.
    c. The management part of the users, slices and experiments.

The ***Reference Architecture*** *technical design* is addressed at two different levels:

- Equipment implementation and "upgrades", able to support experimentation with the latest technology aspects. A key dimension of the hardware components is that a few technologies will be borrowed from the main industrial actors in the field as they solely can prototype them
- Software for facilitating access and usage of the resources.

3.1 Hardware architecture

The facility infrastructure should be designed to be highly configurable and versatile, consisting of several innovative features for both the Radio Access Network (RAN), the backbone/backhaul/fronthaul (X-haul), and the Data Centers (DCs). Regarding the RAN, the deployments shall be organized based on their scale of coverage: femto- and pico- cell nodes, able to cover mainly indoor sites, as well as macro-cell nodes, covering a wider outdoor area, based on the regulated output power. Two different scales of nodes need to be considered; a smaller one, that is low powered and able to be mounted on mobile vehicles, thus realizing concepts of moving cells [4], and a second one that requires higher power and will be mounted on buildings or lamp posts.

These cells will be based on either commercial off-the-shelf (COTS) hardware, for covering the sub 6GHz space, and compliant with the latest offerings of technology vendors. For the latter solutions, implementations taking advantage of Software Defined Radio (SDR) components will be used, able to effectively process high channel bandwidths over the air (in the magnitude of 250MHz per channel, compared to 20MHz that exists today), based on open source solutions of the Universal Software Radio Peripherals (USRPs) coupled with external custom radio-frequency components to satisfy power, duplexing and filtering requirements. In some instances, it may also be economically desirable to make use of fully integrated tier-2 vendor Whitebox solutions which provide higher robustness, better networking and improved RF characteristics. Through such components, enhanced Mobile Broadband (eMBB) and Ultra Reliable Low Latency Communication (URLLC) over the wireless network with high bandwidth links shall be realized. Base stations will be deployable on demand, by instantiating them in the cloud, **offering a plethora of choices for the design and the conduct of new innovative experiments**, such as seamlessly migrating the base stations to other locations, balancing traffic coming from the same antenna to a pool of base stations, etc. In order to address the massive MIMO aspects of the protocol, phased array antennas shall be deployed, able to operate in the mmWave bands [5]. Since future networks will consist of multiple ultra-dense heterogeneous setups, multiple nodes operating with the latest 802.11ad (60GHz band) and 802.11ac/n standards (High Throughput WiFi) should also be considered. The network infrastructure that shall be developed, will leverage different locations and environments, which impacts the reproducibility of the experiments hosted over the infrastructure: 1) provided in a completely isolated setup without any external interference, where experimenters can generate and adjust their own fully controlled external settings, 2) in outdoor deployments, where external interference is uncontrolled, creating a fertile ground for the development of innovative solutions for interference mitigation - also applicable to **cutting-edge research issues** such as full-duplex communications, and 3) a real city wide deployment, offering heterogeneous wireless and optical multi-hop communication in a real production-system.

For the design of the transport network, optical fiber links from NRENs and GEANT should be deployed where this will be available, being able to interconnect a subset of the base stations installed in the facility. Requesting isolated Virtual Circuits from each country's NRENs to the rest of the sites should also facilitate direct Layer 2 connections from each site. Commercial point-to-point and point-to-multipoint mmWave equipment should also be employed for forming a high throughput mesh network with steerable antenna beams for providing Fixed

Wireless Access (FWA) (~2.2Gbps goodput per each antenna sector over the air) [6] from the project's base stations to the core network.

For supporting the experimental infrastructure, Data Centre nodes should be also installed at different locations of the proposed setups; close to the edge, beyond the backbone network, and at different geographical locations, allowing to address all the versatile configurations that currently exist in contemporary networks. Through the application of the AI and ML technologies, services shall be autonomously migrated to compute nodes at the **edge or the core data centers**, depending on parameters such as the network/latency demands of the hosted services, the current load of the network, etc.

Moreover, a large set of sensors and motes, intercommunicating with different manners (e.g. wireless/wired) shall be also deployed massively, towards facilitating the creation of advanced sensing solutions as well as smart-city type of environments. These sensors shall support different protocols for communication, reachable from everywhere (e.g. using 6LoWPAN), and collecting a wide variety of measurements, hence addressing Internet of Things (IoT) aspects. Their connectivity will rely on protocols for either short range communications (e.g. Zigbee, WiFi) or the formation of Low Power WANs (e.g. 5G-NR, NBIoT, LTE-M, LoRaWAN). These measurements shall be either environmental (e.g. light intensity, CO2 emissions, sound sensors, etc.) or presence (sonar based e.g. for determining whether a parking spot is empty).

3.2 Software architecture

The RA should allow for fully programmable remotely accessible infrastructure to the Digital Infrastructure community, the respective frameworks shall be developed for ensuring seamless and easy access to the experimental resources. The different site facilities will form an integrated single pan-European facility, adopting common tools for managing and orchestrating experiments over the infrastructure, as well as providing a single access and credentials to users. The reference architecture with respect to the tools used for its management, is described in Figure 4 and Figure 5.

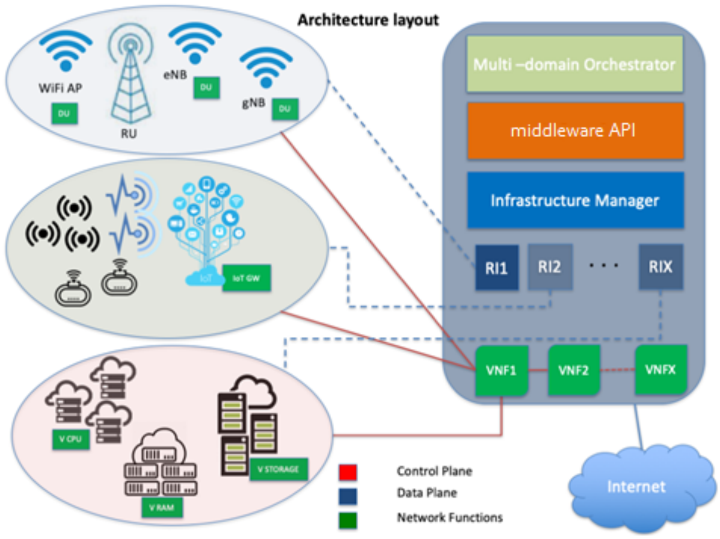

Figure 4: Target Reference Architecture

Towards achieving this integration, the sites should adopt network virtualization for their resources, compatible with the Management and Orchestration (MANO) architecture [6] for managing and deploying new services over the physical equipment. Each node will be considered as a single domain for experimentation, while the overall orchestration of experiments will be performed through a centralized infrastructure. Site and node selection frameworks will be developed so as to ensure the optimal use of resources among the sites.

Moreover, and towards ensuring the smooth operation of the infrastructure, tools for facilitating access should be developed and deployed. Open source software shall be employed, based on the paradigms of existing testbed access schemes, user authentication and authorization. This software will be appropriately tailored with new modules for managing the new equipment described in the previous section.

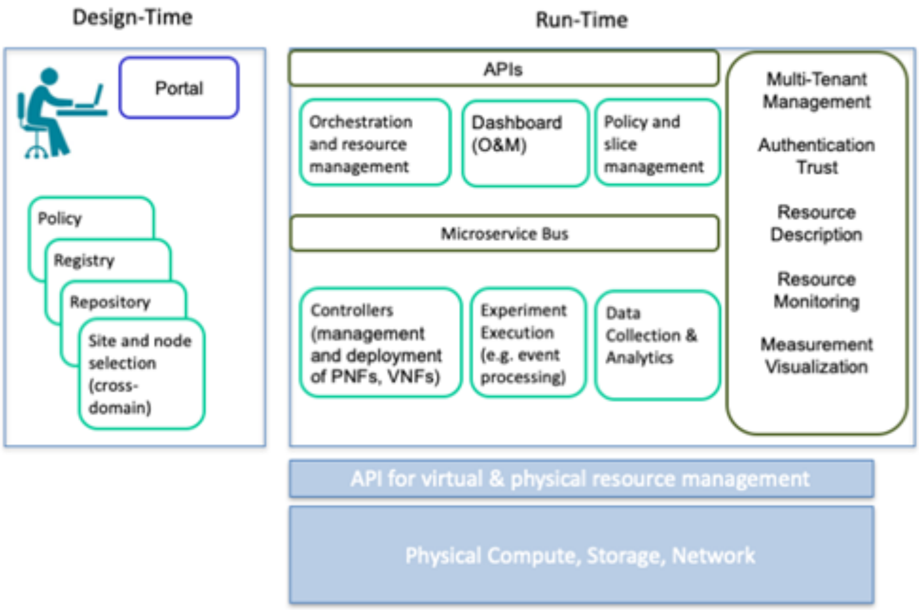

Figure 5: Software architecture and tools for experiment design and run-time

In terms of integration of the various components, the software tools shall encompass single sign in procedures, with access certificates issued by a single authority. The resource discovery, reservation, and allocation shall comply with the adopted access policies and be interchanged with the respective facility authorities through a standardized process. For this purpose, the SFA [7] protocol has been extensively used in past and present solutions and could inspire the candidate solutions together with new complementary or alternative solutions that will be considered as well.

Moreover, and towards realizing the full potential of the recent technology trends for network virtualization, the RA will employ the Management and Orchestration (MANO) architecture for managing and deploying new services over the physical network. Through MANO, services and network elements are packed as Virtual Network Functions (VNFs) which can be instantiated over physical equipment; the same physical equipment can be used to execute different VNFs, whereas multiple VNFs can be instantiated over the same piece of hardware, thus allowing the equipment to be virtualized and shared among different operators (multi-tenancy). As the network infrastructure relies greatly on software, even for the RAN realization, the efficient and simple management and orchestration of these VNFs becomes of paramount importance.

Based on the automation tools complying with the MANO architecture (e.g. OpenSourceMANO [8], ONAP [9]) and combined with cluster-orchestration tools such as Kubernetes [10], new experimenters should be equipped with a store in order to easily and readily deploy services over the infrastructure. This can be achieved with these frameworks by using pre-compiled versions of services, and by supporting different methods for virtualization of resources (e.g. Virtual Machines, docker containers, Linux Containers). For example, public docker repositories provide different images that can be used to deploy commonly used services (e.g. databases, web services, applications and application servers) through a friendly interface. Capabilities should also be provided in order to support remote learning, enabling virtual labs based on advanced technologies that are barely available on site and therefore, will contribute to education and developing skills in a very competitive environment. Moreover, the entire architecture will be augmented with the appropriate tools for experiment monitoring, experiment data and results visualization and cross-correlation analysis and inference with previous experiments executed over the infrastructure.

3.3 Reproducibilty and AI

Empower decided also to set up two other important initiatives tightly elated to our vision and roadmap.

The first one deal with Reproducibility[1] and is already organized. Repeated research is an important part of scientific methodology. Repeating or replicating research not only brings an independent perspective to the investigation, but also provides a basis for comparing different approaches and extending known results. The process of repeating others' research also allows us to learn, not only from their insights but also their experimental methodology. Replication is thus an important facet of scientific debate. Up until recently repeating computer science research, while desirable in principle, was often difficult in practice. This is due to several well-identified factors such as the lack of incentives (e.g., in publication venues) that value such effort, lack of common research platforms and tools, and the difficulty of packaging the requisite digital artifacts in an easily shareable form and the mechanisms to combine and publish them. Change is needed.

The objective of the "Empowering Repeated Research Initiative" is to create a forum that catalyzes such change. We envision two complementary activities to be undertaken in this initiative, in the short and longer term. A first set of nearer-term activities include a series of workshops (see below) educating students and involving faculties in the art of reproducible research, and identifying and developing a set of tools and best-practice-techniques for enabling reproducible research. We would like to invite submissions that repeat results published in past papers and provide a brief analysis of the results as well as the ability to replicate them, similar to "Xen and the Art of Repeated Research" by Clark et al. The repeated results can range over a variety of computer science systems topics such as: wireless, networking, operating systems, distributed systems, cloud computing, and others. With the emergence of generally accessible testbeds, technological innovations such as containers, virtual machines, or computational notebooks, repeatability can be both easier and an inherent part of the discovery process. Submission on these tools and experience with them are also welcome. Consensus best-practice techniques will emerge from these workshops. The longer-term objective is to to reach out to the main stakeholders, professional societies and conferences, with recommendations arguments and potential solutions for embedding reproducibility in the research life-cycle.

Empower will set up a series of workshop, with regular presentation, demos, panels and discussion. These will be organized virtually but additionally collocated with conferences and workshops when possible. Each event will be prepared by a small group of colleagues who will set up the agenda, organize the debate and synthesize recommendations. A continuous "challenge" will be organized with an award to recognize important "hands-on" contributions in the field with a strong emphasis on student involvement.

The second initiative is just under construction together with the US side and is discussing the place of AI in the test platforms and related research topics. We expect this topic to develop during the next period.

4. EMPOWER as a coordination point for EU and USA researchers

One of the key objectives of EMPOWER is to serve as coordination point between researchers across USA and EU, with special attention to the coordination in the development of advance wireless experimental platforms. Following this objective and the mission of EMPOWER of bridging the research in advance wireless platforms across the Atlantic, we organized a set of scientific missions between European and USA key researchers in the area. The main objective of these first missions was to get a detailed view of the different platforms being developed in both geographical areas.

[1] https://www.advancedwireless.eu/index.php/reproducibility/

Following this idea, a delegation from PAWR and NSF planned to come to Europe to meet the selected facilities (Madrid, Sophia Antipolis and Oslo) and discuss about experimentations with some of the scientists running them. The visit was planned the week of 9-13 March 2020. Unfortunately, due to the COVID-19 outreach, some of the US participants cancelled their physical presence at the last moment. In addition, the visit to Oslo was cancelled due to the USA government closing the borders to European flights.

The NSF delegation consisted of Abhimanyu (Manu) Gosain, Technical Program Director of the PAWR Project Office (https://advancedwireless.org) who also acts as the liaison with other large-scale NSF projects, and Ivan Seskar, Program Director of the COSMOS Project (https://www.cosmos-lab.org).

Even if the visit had to be cancelled before its conclusion, the outcome in terms of coordination and future activities was very positive. In the following, a summary of the scientific missions is presented.

- The first of the advance wireless platforms visited was **5TONIC** in Madrid, the open research and innovation laboratory on 5G technologies, founded by Telefónica and IMDEA Networks. The visit was divided between pure technical discussion on the research performed using the 5TONIC platform, discussion on the EU H2020 ICT-17 projects developing end to end platforms including 5TONIC and finally models for collaboration between the platforms. The technical presentations and demonstrations were focused on i) mmWave access, ii) real time close-loop control of robots, iii) visible light communications, and iv) mechanisms for crowdsourced spectrum data analytics with low-cost spectrum sensors and big data architecture. Following these technical aspects, the ICT-17 end to end platforms 5G-EVE, 5G-VINNI and 5GENESIS were able to present the deployment aspects of each platform and their evolution paths. Finally, discussion between the different attendees regarding how to foster collaboration between researchers and platforms was also held. Main action points to consider for this first step on the scientific missions include:
    - Interactions between COSMOS and 5GENESIS towards the use of the 5GENESIS control framework to remotely control resources at COSMOS from the 5GENESIS control infrastructure. This will allow to setup combined experiments across both infrastructures.
    - Experimental collaboration between ARENA and 5G-VINNI. The objective of this activity is to setup an NSA network consisting of a 5G Core in 5tonic and a gNB in ARENA. Current tests show 280ms as the maximum delay for MME connectivity, which is attenable between ARENA and 5TONIC.
    - Analysis of the possible similarities between 5TONIC 5G deployment and the test site being deployed in North Carolina. Apart from specific hardware configurations, 5G-EVE has developed some scripts to record measurements and export KPIs, which is something that might be replicated in other test sites.
    - Collaboration with EMPOWER. PAWR projects are already recording webinars on how to use the different platforms. Practically, EMPOWER can serve as a neutral playground to have webinars of all platforms. This point is under study.
- The second of the advance wireless platforms visited was Sophia Antipolis and EURECOM. This test-site forms part of the 5G-EVE facility. The two-day visit started with presentations by the managers of the French 5G-EVE facility and Sophia Antipolis site, Rodolphe Legouable (Orange) and Raymond Knopp (EURECOM), on the project status and French facility capabilities. This was complemented by Adlen Ksentini (EURECOM), the manager at EURECOM for the 5G!DRONES ICT-19 project, who presented a use case of the 5G-EVE Sophia Antipolis site, namely 5G-Slicing for UAV communications. Francesco Mani (EURECOM) followed with a presentation of the current status of the OpenAirInterface (OAI) open-source 5G implementation followed by live demonstrations of outdoor 5G links using the OAI RAN and Core on the 5G-EVE facility. Navid Nikaein (EURECOM) presented an additional demonstration of Kubernetes Operator-based deployment of OAI. The participants from the US and Europe discussed several collaboration opportunities at the meeting aiming at mutualization of USA PAWR resources. These included for testing OAI-based solutions for 5G deployments at POWDER and COSMOS, integration of OAI RAN and Core software with ONAP infrastructure at COSMOS, and replication of 5G NR FR2 (mmWave) configurations currently used at the French 5G-EVE facility at all the PAWR sites in the USA.
- The last stop of the scientific mission was planned to be Oslo and 5G-VINNI Norwegian facility, which is managed and hosted by Telenor Research, where different demos on how use cases are implemented and tested on the platform were shown to the US delegation. Unfortunately, this part of the visit had to be cancelled, due to COVID-19.

5. Conclusion

This Whitepaper reports the work done in the H2020 EMPOWER project towards fostering the collaboration between the USA and the EC in the Advance Wireless platforms development. This Whitepaper discusses two key working items which have been subject of deep discussion between USA and EC researchers: i) the analysis and identification of technological trends towards 6G and ii) the discussion on the need of a common reference architecture to foster repeatability of experiments and reuse of software tools. These two working items have been key in the ongoing discussion of EMPOWER and will be subject of future work.

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