1.1 *SCIENTIFIC SCOPE AND CONTENTS OF THE PROJECT FOR THE NEXT FINANCING PERIOD*

The main novelties for the 5-year extension are the following.

- The scientific roadmap is updated to account for the rapidly evolving context of the digital society. In particular, we extend our scientific portfolio to five tracks with additional emphasis on big data, artificial intelligence (AI) and robotics, and on AI for education.
- To strengthen our education program, we create calls for thematic schools with the same demanding selection process involving the IAC as the project selection one. They will feed our doctoral curricula in relation with UBL MathSTIC doctoral school.
- We launch an international program including international mobility for the CominLabs Ph-D students, and international chairs.
- We will enforce our follow-up action program for innovation and industrial transfer.

CominLabs proved to be an outstanding means to build and develop ***transdisciplinary communities*** by creating synergistic series of projects. Such communities were created by following a mixed top-down and bottom-up approach. Research qualified as "would-not-happen-without-CominLabs" was emphasized. In 2015, CominLabs research was structured into three research tracks: Security and Privacy, ICT for Health, and Communications, with the remaining CominLabs projects being related to the broad area of data sciences and images.

Figure 1 : The five tracks for 2020-2024

As illustrated in Figure 1, two additional tracks will be established: ***Data, AI & Robotics***, partly developed in the previous phase of CominLabs; and ***AI for Education***, which will structure the activities in ICT for education. The previous track ICT for Health is refocused on ***ICT for Precision Medicine***. The two other existing tracks are renamed as respectively ***Waves, IoT & Networks***; and ***Trust, Privacy & Security***, reflecting the evolution of their focus. ***Humanities and social sciences (HSS) are involved in these domains***. Studies on ICT in HSS will include the user's point of view, and the impact of these technologies on economy, public life and political space (legal, economics, social issues). Following this policy, CominLabs will continue creating new groups in the broad areas above, in an opportunistic way depending on available assets and emerging new challenges. Of course, these five tracks will not operate "in silos", but will be able to interact and generate projects at the interfaces. CominLabs policy regarding patents, industrial collaboration, and start-up creation, will be pursued and strengthened. ***Below, we develop the most prominent challenges*** that CominLabs considers in its extension period for these five tracks.

2.1.1. Waves, IoT, & networks

The main assets of CominLabs in this area sit in the lower layers (microwaves/photonics and digital communications) and over-the-top layers. This is reflected in the portfolio of CominLabs projects and is taken into consideration for our future agenda.

New systems and services in 5G and beyond call for ***highly efficient, possibly reconfigurable, radio frequency (RF) front-ends*** with innovative and versatile microwaves/photonics circuits and antennas able to operate in rapidly evolving environments. Small size and weight, and low power consumption require innovative design approaches and advances in materials. New massive MIMO systems are needed up to (sub) millimeter waves, typically for 5G and beyond 5G use cases, with ultimate challenges at the RF and base-band levels. Adaptive radio front-ends for communications, radar, or surveillance applications require highly tunable circuits and antennas, along with accurate channel and wave propagation models. CominLabs will focus on education and research at all levels, from advanced material studies, to individual building blocks (with a priority given to radiofrequency front-ends), subsystem- and device/system-level analysis, design and optimization.

Due to the advent of IoT, flexibility in communications needs supporting a plurality of standards, fostering new research challenges in both electronics (reconfigurability) and communications (cognitive radio). Decentralized and autonomous networks with heterogeneous ultra-low power devices making energy harvesting, as well as robust D2D devices with QoS expectations, demand innovative electronics and radio solutions in both LPWAN and NB-IoT contexts. A global security issue arises with this multiplicity of connected devices. Distributed green radio has also to be developed. To improve system autonomy, CominLabs will foster both disciplinary and transdisciplinary projects: at the technological level by designing ***new harvesters and non-volatile memories***, at the architecture level by designing ***normally-off architectures***, and by using ***non-conventional arithmetic*** (bio-inspired, approximate computing).

Robustness and adaptation should also be addressed over-the-top (OTT). The Descent project, on efficient and reliable editing on distributed and decentralized clouds, shows that artifacts and weaknesses of the communication infrastructure can be mitigated at that level. This is of course context dependent – e.g., distributed editing requires a weaker form of consensus achievable in larger contexts. Pervasive RFID project illustrates the relevance of combined solutions at antenna and OTT levels to offer interesting solutions and services. This suggests work directions for CominLabs to ***improve robustness and adaptability at the OTT level***.

2.1.2 Trust, Privacy, and Security

Privacy and cybersecurity has been a major focus for CominLabs since its beginning, thus contributing to the strength of our geographical area in these sectors. We addressed challenges in data protection, security policies, software and hardware vulnerabilities and protection mechanisms, with a focus on web applications and cloud computing. Ten research projects and follow-up actions have been built.

For the next period, we will extend this focus by including issues related to ***trust***, for which researchers from Social Sciences (in particular psychology and law) will contribute. The level of online security is affected by technical factors, contextual events but also by human behavior. We will study the legal and technical implications of the recent European Data Protection Regulations. In particular, we will investigate how to ensure that the exploitation of data will be in accordance with law and who will assume responsibility in the event of a security breach.

Secure decentralized infrastructures for the society is emerging as a critical issue with the advent of the IoT and applications of the blockchain. CominLabs will address this by building on its assets on formal methods, programming languages, cryptography and distributed computing. Recent advances suggest that it will be possible to manage and share information in an open, transparent and

dependable way, under users' control, thus providing a vision ***beyond the blockchain***. CominLabs will continue strengthening its activities in this area by developing a lighter-weight decentralized consensus mechanism, thus contributing to the improvement of a fundamental pillar of the blockchain. ***Data security at hardware level*** is getting a critical technology. Attacks and intrusion on hardware can be carried out in many ways, from software to electronics by using side channels, laser fault injection, and electric or electromagnetic means. CominLabs will investigate ***resilient cryptography*** (e.g., with chaos-based crypto-compression and lattice-based cryptography), and will develop secure HW/SW implementations of cryptographic primitives and protocols.

2.1.3 Data, Artificial Intelligence, & Robotics

The ***deluge of data*** and the advent of ***deep learning*** have raised the digital society. The large ***deployment of robots*** should be the next step**.** The latter motivates the extension of CominLabs scope to robotics, especially since several partner labs comprise renowned robotics teams. One of the major goal for the next period is to launch projects exploiting links between the three domains of this track.

High-performance computing (HPC) approaches could contribute to push big data solutions to higher performance levels. Conversely, data analytics will become a fully-fledged software component of the HPC ecosystem. CominLabs will leverage partner labs expertise in ***distributed data management and distributed infrastructures*** to investigate advanced data storage, management and analysis. Regarding ***physical modeling and data processing*** and their coupling, CominLabs will collaborate with teams in geophysics and biology, where fast progress in imaging technology provides huge amounts of data. CominLabs will keep on stimulating transdisciplinary research and training at the interface of artificial intelligence and ocean science with EUR IsBlue, the interdisciplinary graduate school for the Blue Planet recently awarded to take over MER Labex for the next 10 years.

The ***image & video*** part of the track relates to booming public, personal and professional contexts. It involves ***future video formats*** for an amazing immersive experience, including light fields, and ***green and secure*** video compression and transmission, especially for IoT. CominLabs will leverage machine learning and knowledge representation for new ***media production and consumption experience,*** while adopting a cross-disciplinary perspective encompassing technology and usage. Research on interaction will address both ***3D interaction*** with innovative multimodal interaction metaphors including brain computer interfaces (BCI) and haptics, and ***human-robot and multiple robots interactions.*** CominLabs will merge expertise of its teams in robotics, visual servoing, computer vision, sound and speech processing, artificial intelligence to tackle the latter. Solutions to human-robot interaction will rely on multimodal interfaces while taking into account societal issues. Research on multiple robots aims to achieve complex coordinated tasks or to explore hostile environments.

2.1.4 ICT for precision medicine

Considering the results of the 2012-1018 period, ***precision medicine*** has emerged as a major focus of CominLabs in the e-health area, with five projects, one start-up, two phase-III clinical trials, and collaborations with the CAMI and GENMED Labex in the health sector. CominLabs will benefit from the strong interactions established with biologists and clinicians, the availability of up-to-date hospital and Eugène Marquis Cancer Centre platforms in Rennes, Brest and Nantes, the long-term partnership with major industrial players (LivaNova, GEMS, Philips, Medtronics, Ansys, etc.) and SMEs (Imascap, Therenva, Medecom and others). It will offer resources needed for all the steps in the process from research to innovation and assessment through demonstrative clinical trials.

For the next period, CominLabs will explore new paths to address breakthrough issues in precision medicine, for instance in mobile-health through IoT, in heterogeneous big data management and exploitation with the required secure storage and access, in image-guided robotics. ***New devices and training techniques***, with secure distant access and control, will play a major role. We will work, in particular, on brain interfaces with real/virtual-brain-in-the-loop experiments, and virtual reality technologies for training medical staff. ***Multi-level and multi-physics modeling and simulation*** will be required to develop multimodal and multi-scale imaging for optimized therapy. CominLabs will work on cancer radiomics and acute heart disease, improved minimally invasive interventions and multiphysics therapies. The development of such modeling techniques will be complemented by techniques from ***artificial intelligence and big data analytics*** to handle the huge amount of data issued from biology and medicine. The competences gathered in CominLabs through data science, deep learning and information processing will be used for designing innovative approaches.

2.1.5 Artificial Intelligence for Education

In its 2018 report on Artificial Intelligence, the Villani committee suggested that R&D in AI in France should focus on five topics. ***Transforming Education*** is the first. The Sustainable Development Goal 4 by the UNESCO in September 2015 calls for "Ensuring inclusive and equitable quality education and promote lifelong learning opportunities for all". Many universities are now creating "Learning Labs", as the discovery learning laboratories at EPFL. The difference with previous pedagogical centers is the increasing presence of technology and data allowing an approach triggered and analyzed by the social sciences but driven by digital science. The emerging area of Ed-Tech offers opportunities for new companies; see Educate in London. Online learning represented 260 billion dollars worldwide in 2016 (about 1 billion in France), with Internet giants and new players as OpenClassroom.

So far, CominLabs devoted resources to foster research linked with the use of computing technology in education, even contributing to the training of teachers for coding and computational thinking (ClassCode in Brittany). CominLabs is thus in a strong position to contribute to the field of AI for Education with several researchers well known in this field, others more active in enabling fields of AIED: Cloud Computing, Security, Machine Learning, Semantic Web, Human-Computer Interfaces. There are social sciences groups who are already working with a Learning Lab approach. Commitment of CominLabs to these questions over the past few years has been instrumental in allowing our teams to collaborate, submit, and receive EU and French (ANR) grants (X5-GON, Pastel, Hubble).

CominLabs will focus on the following issues for its future period. ***Intelligent and interactive technologies in an educational context*** involves natural language processing and speech technologies; data mining and machine learning; knowledge representation and reasoning; semantic web; multi-agent architectures; tangible interfaces, and augmented reality. ***Models of teaching and learning*** involves intelligent tutoring and scaffolding, educational data mining, learning analytics and teaching support, learning with simulation, and large-scale deployment of AIED (Artificial Intelligence for Education) systems. We will also address issues like ***evaluation*** and applications to specific fields, e.g., medicine. These questions will also allow for experimentation in the wild, in Universities and Schools inside CominLabs, or through the Unesco Chair at Nantes University on Open Educational Resources.