CELTIC NEXT 2021-2025 Mission, Vision & Roadmap

Next-Generation Communications for a secured, trusted, and sustainable digital society

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CELTIC NEXT 2021-2025 Mission, Vision & Strategic Roadmap

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1. CELTIC-NEXT Mission, Rationale, and Vision

1.1. CELTIC NEXT's Mission

The mission of CELTIC-NEXT for the next 4 years is to foster our Eureka collaborative RD&I program for the ICT community, and to accelerate the deployment and take up of advanced ICT services, employing the new network concepts of 5G and leading to the ownership and implementation of 6G in Europe. It is crucial to consolidate the position of European manufacturers and service providers, with a high degree of European sovereignty, as globally leading suppliers of the advanced ICT equipment and services needed for the digital revolution.

It is a strong ambition of CELTIC-NEXT to assist European National Authorities, European Industry, and European Societies to access the societal benefits, competitive advantages, and commercial returns of being at the forefront of the new digital society.

Specifically, CELTIC-NEXT will actively encourage the ICT industry collaboration with other industry verticals to facilitate the adoption of the advanced ICT technologies into the business models and processes of all industry sectors. The focus of the CELTIC-NEXT approach is to consider the issues in a holistic way considering the "end-to-end" perspective of the new communications services – including an understanding the economic, environmental, and societal benefits and the new extensive use of data. Over recent years the environmental aspects of using advances communications services not only to monitor and supervise energy consuming activities, but also to investigate where advanced communications can improve business models and processes by replacing activities with ICT services and thereby reducing carbon footprints for many sectors.

The new CELTIC-NEXT approach will continue to use the successful bottom-up industry-driven technique, aligned with supporting large focused "flagship" initiatives solving specific issues of strategic importance, and also supporting new Thematic issues as and when they arise in the Eureka cluster community. The unique eureka approach of developing a combined and coordinated strategy between public authorities and industry to achieve both national ambitions and commercial goals in an efficient way has been shown to enable new technologies and new markets in an easier and faster manner than other large pan-European programs.

CELTIC-NEXT's successful track record and background

In 2018, the EUREKA High-Level Representatives decided to renew the label for the CELTIC-NEXT EUREKA Cluster. At that time, everyone listened to music and watched online videos on their mobile devices anywhere and anytime, and both businesses and individuals had their data stored in large data centres located all around the world. Since then, COVID responses have increased the reliance on communications infrastructures as a core part of the ongoing operation of industry and society.

CELTIC-NEXT brings the major European telecommunications vendors and operators together into an ambitious European intergovernmental R&D programme that tackles the main means related to an end-to-end approach in communications. It was and remains the best option to address the necessary "system" and "system of systems" views of communications to complement the other existing Clusters. It constitutes one of the three pillar clusters, together with hardware and software, supporting more horizontal or use case driven communities and their clusters, present and future.

Celtic, through its renewals as Celtic-Plus, and then CELTIC-NEXT has been key for initiating ambitious and innovative projects dedicated to end-to-end communications solutions.

Until today, the successive Celtic clusters generations have labelled, funded, and performed in little less than 18 years, over 150 projects in all their research areas with a total volume of more than one Billion Euro. By facilitating these collaborative R&D projects, they have made a great contribution to help Europe to stay at the competitive edge of the telecommunications industry.

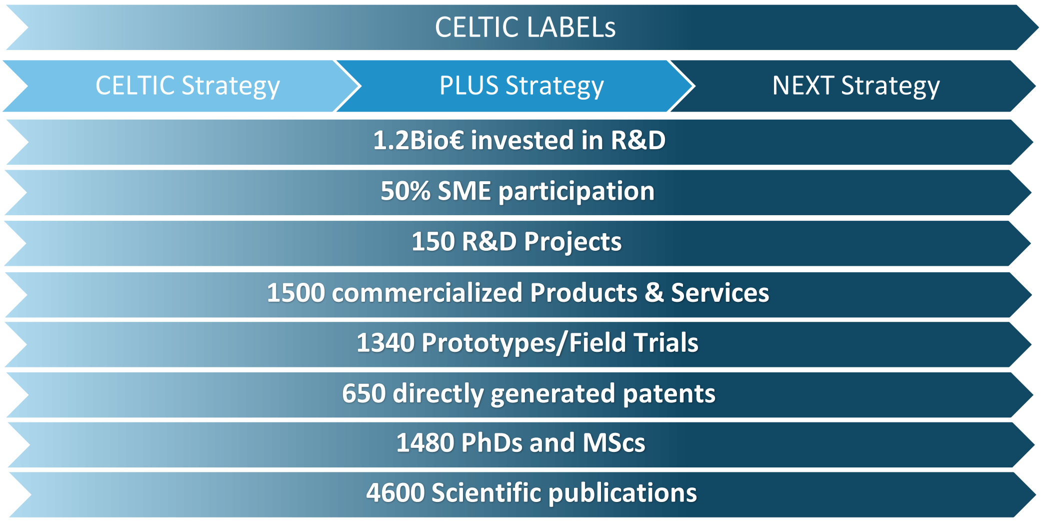

Figure 1 : Past and current (pre-ECP) Celtic Cluster's Programmes' impact

The participation of SMEs in Celtic has continuously increased throughout the years, to reach more 50%. In 2017,

Celtic-Next and its fellow Clusters have contributed significantly to the growth of the annual turnover of firms involved in Cluster projects (+13% compared to nonparticipating firms) and to the development of employment (+7% employment growth compared to non-participating firms).

the total budget of SMEs in Celtic-Plus projects overcame the total budget of large Industry[1], [2].

This document provides insights into the scope and main research areas, which CELTIC-NEXT projects should focus on. The research areas in this document, however, are not binding. CELTIC-NEXT follows a bottom-up, industry-driven approach, which allows proposers of CELTIC-NEXT projects to define the content of their project proposals according to their own research interests and priorities.

1.2. CELTIC-NEXT's Rationale for 2021 - 2025

There are a number of critical technological and techno-societal issues that need to be addressed in the coming years that are not addressed by other EUREKA instruments, and only partially by other research instruments in Europe. From a technological standpoint, Networking and Cloud Enablers addressing and using technology from

[1] "Industry" in the sense of Celtic-Next excludes telecommunication operators.

[2] "Impact Assessment of EUREKA Network Projects and Cluster Projects – Main findings and recommendations". Berlin/Brussels/Graz, May 24, 2017

such areas as cyber security, artificial intelligence, 5G and beyond, 6G, FinTech, Big Data, business analytics, and IoT are considered as important orientations to develop.

A special focus of CELTIC-NEXT will be on connectivity applications and services serving the vertical sectors such as content (video, gaming), e-health, smart cities, agriculture, mobility, energy, automotive, e-commerce, and industry 4.0 / manufacturing / logistics. Those verticals are equally important to advance, along with optimising and improving efficiency and reliability with the best end-to-end connectivity and security. The evolution of ICT services over the next period will be achieved via a partnership model where the vertical sectors collaborate in determining their ICT solutions, achieving cross-fertilization between verticals and ICT communities. This will be a key focus of the CELTIC-NEXT end-to-end perspective. Another key issue for CELTIC-NEXT will be to develop communications infrastructures and services that can adapt to the requirements of various business sectors. The needs for communications between vehicles are indeed quite different than the needs for piloting electrical power in buildings and houses. The same applies to the virtual and immersive reality techniques that will become a critical element in the health and media industry in the coming years. There will also be many unique challenges behind innovative manufacturing processes that must be supported by one ubiquitous infrastructure.

New communications themes will emerge in the next period to consider the impact of the revolution in media and social networks. We can expect that the ICT community will have to address issues emerging from the dramatic impact of fake news and false information dissemination where lawful techniques will be needed to combat misuse of communications and to re-establish trust in the fully interconnected society of the future.

Another big change causing a dramatic uptake in the use and deployment of ICT services in 2021 has been stimulated by the global and national responses to the COVID 19 virus outbreak. Virtual meetings and home working are now the new normal and it is quite likely that these shifts to ICT based operations will remain a core part of future operational strategies for all aspects of our working and social lives for the foreseeable future. This increases the pressure to ensure we have the most performant, reliable, secure, and cost-effective communications infrastructures to support our businesses and society going forward.

We expect that many of the CELTIC-NEXT projects will define and develop self-adaptable solutions, able to fit the needs of many different sectors and societal challenges. CELTIC-NEXT with its end-to-end approach is key for allowing the development of dedicated applications using the network with all the required features for a given economic sector. Representatives from vertical sectors will be progressively invited to participate in the CELTIC-NEXT Industry Core Group to ensure the continuous cross-fertilisation of ideas. In parallel, the telecommunications industry shall exploit the full power of cross sectors technologies such as Artificial Intelligence and Big Data, to define and provide customised and smart solutions for the different economic sectors and society as a whole.

Global changes and lessons learnt since 2018’s planned program

Aligned with, and extending from, the CELTIC project observations and lessons learnt in the last period are the global changes which need to be considered when evolving the CELTIC-NEXT vision. 2020-2021 have been proving to be the most dramatic year for our generation, as we struggled to come to terms with a global pandemic. And we understand also that it will not be the last one that humanity will be confronted to. The large societal impact of, no travel, limited social contacts, and prioritization of all medical resources, has prompted a total review of priorities among all communities and industries. It has altered the perceived importance of many of the environmental factors that were, until now, addressed as supporting elements of evolutions. It has challenged us to consider how, in advancing the communications infrastructure for future communities and industries, we can build more sustainable and resilient services not only tackling topics like pollution, energy shortage, climate change, etc., but also considering how societies should be organized to become resilient to such disruptive events as a global or national pandemic in the future.

Recently, the ICT industry has been accelerating developments in an exciting industrial cycle driven by the new requirements of pervasive media (including social media), sports, entertainment while maintaining basic services like Voice, Texts, and Internet browsing. The global trend that promotes digitizing "everything" – including the Economy, the Government and Education services have been based mapping digital services to their real-world equivalent services, rather than promoting any real changes in user behaviours.

What is quickly being learnt as we assess “digital everything”, with a special focus on Digital Education, Digital Government, and Digital Economy is that as soon as volumes increase the performance demands on the infrastructure increase proportionally. When you give the digital capability to users, they quickly find new and demanding ways to use it for services that were not originally thought of. This creates the challenge of maintaining the quality of service as the roll-out develops. 5G has promised to be more efficient than precedent generations as bandwidth or throughput per Hz. However, 5G can only deliver its full promise if the deployment, which has a huge cost, is grown in line with the customer base and their usage patterns.

Open RAN architectures and hybrid 5G infrastructures (public and private networks) will offer some solutions but they also add complexity and costs to the operation of the infrastructure. Therefore, most 5G testbeds and experimental projects have a business case modelling activity to contribute towards the elaboration of the overall business case validation for a full deployment of 5G, thus enabling the foundations and the funding of the next generation of ICT systems, being Beyond 5G or 6G.

5G also promised to reduce the energy consumption by a factor of 1000 in order to balance the higher density deployment of equipment against the increasing energy bill. There is still a lot of work to be done on both a systems and components level to address this challenge.

At this stage of experiments and feedback from field trials, it is clear that 5G, or even 6G, will not be the only technologies used for future communications infrastructures. Recent new Wi-Fi developments and other short-range communications can also play a role in serving the vertical sectors and public needs. There are new challenges now to ensure a harmonious convergence of network technologies can be achieved to offer the best overall experience to the end users and a good return on investment to the operators.

CELTIC-NEXT is focused on helping to provide this network of networks, this system of systems, able to deliver all needed services in an efficient and cost-effective way.

This integrated network approach, allowing the plug and play of network components, has actually stimulated several initiatives to define interfaces in the network that create more space for competition in the supply chains and thereby reducing operation costs and fostering more innovation. Typical examples would be the Open RAN and TIP initiatives. Large enterprises, SMEs and even start-ups have jointed these initiatives as they revitalize the innovation landscape and allow small enterprises to compete with traditional network equipment providers in new, but sustainable, business models.

The first generation of vertical experiments and trials the testing advanced ICT infrastructures in a range of industries like manufacturing (volume or high value), logistics, etc., are now producing results based on measurement. Clearly significant achievements have been recorded in the provision of wireless infrastructures that allow the movement many industrial processes from static to at least nomadic if not full mobile scenarios. As the capability to work over wireless becomes proven, the challenge moves to determining if the low latency capabilities of wireless infrastructures will evolve quickly enough for industry to adopt 5G as a pervasive technology for all applications. The affordability of a private 5G network complying with those tight performance requirements is also an open question. Therefore, there is an increased demand for a deeper collaboration with verticals in new and more advanced experiments to test and validate these real-life requirements.

CELTIC-NEXT is absorbing the new post pandemic requirements.

Covid-19 presented a number of short term and long-term challenges to the world. In the short term we had new requirements like for the "Track n' Trace" applications, using the available ICT infrastructure and devices. This generated many challenges as it highlighted the conflict between protecting private data and sharing data for the common good.

One of the positive lessons learnt from the COVID-19 crisis is the fact that technology should predominantly support humanity (societies), down to each individual (prevent isolation). But there is also an issue here about the unwillingness of a significant proportion of the public to allow support technologies (5G roll-out, location tracking, etc.) that needs to be addressed. We may need more CELTIC-NEXT experiments to demonstrate positive successful examples of ICT technology implementations and usages which can help national Public authorities to show by that the new technologies are positive and only used for helping people.

Also in the short term, many educational courses in universities and schools everywhere, changed from physical presence models to teaching via videoconference. Enterprises, schools, universities, administrations had to move to home-working or remote-teaching modes of operations. This challenged the infrastructure providers to ensure everyone had a good enough communications service – at the same time and all the time. There is no doubt that many of these “emergency” models will remain as "standards" after the crisis. It implies a huge social change in mentalities regarding work and physical presence from employees and students, as well as managers and teachers. The permanent acceptance of the remote working models will place significant demands on future networks to support faster and simpler moves between the various modes of operations. CELTIC-NEXT can offer a flexible innovation space to develop and trial such innovations through collaborative that would facilitate countries sharing same or complementary approaches to these new demands.

One sector of the economy that has been massively impacted by the COVID restrictions is the retail sector. Supply chains were disrupted by the absence of staff, transport disruptions and even the total closure of retail outlets. This was compounded by irrational behaviour from consumers in many markets “panic-buying” many consumables. Many shops and shopping centres, as the endpoints of the supply chains, have had to adapt the new "normal" by **re-inventing the way they connect** with their customers and the way they deliver the services to them. Many have moved online, providing home delivery or “click and collect” services. ICT technologies have been immensely useful for this, and more innovation can certainly still help in making those operations smoother. While it is not clear that this will be a permanent shift of services online, there is a possibility for higher power ICT applications such as virtual presence and even haptic sensors to facilitate the remote shopping being a better experience in the future.

Another section questioned in the dramatic upheaval is the manufacturing sector. Years of outsourcing manufacturing to cheap labour markets and exploiting cheap travel costs for shipping the goods have been highlighted. The question now is if the model needs to change. 3D printing and automation may mean that manufacturing can be distributed to local centres rather than being centralised on a global basis. This will reduce costs, travel requirements and environmental impacts. Production of critical goods and services may need to become fully automatized or at least done by machines (remote controlled for example) to prevent another pandemic type of incident from stopping the production of fundamental goods for human societies.

The travel restriction aspect of the current pandemic response has generated demands for new technologies and services. It has become more evident now that borders should become smarter and more dynamic to react rapidly to changes of rules on the movement of people and the shipping of goods.

Beside the evidence of the need to accelerate identified sectors like supply chain management, logistics, manufacturing, education, government, there should be an equivalent acceleration of the digitization of all sectors of the economy that can benefit from it. Therefore, the bottom-up approach of CELTIC NEXT calls can also help nonmainstream services to accelerate their digitalization as they request funding for innovative applications and can connect with experienced ICT companies to help them to achieve that.

Through all the above topics, and in the vison of CELTIC-NEXT, Cybersecurity is an essential dimension of future communications. This is not only to secure services but also to counteract disinformation strategies for political or commercial gains. CELTIC-NEXT will recommend all projects to consider this dimension. There are common system security requirements across vertical service scenarios but there are also very specific ones related to specific services and devices attached to the network. And this is a larger topic than just the networks as fixed network connectivity and both intra and inter data centres connectivity are also at risk.

The complexity of future networks, because of the huge number of inter-domain and inter-technology connection points between so many network elements, will inherently have to consider the system vulnerability. System implementation strategies must consider how to:

- Reduce the possibilities of malicious attacks,
- Limit the impact of elemental failures,
- Ensure there are no backdoors in the European Network,
- Ensure users understand and can trust the network.

A new development in the political environment has recently occurred where the origin of technologies in the communications infrastructure has emerged as a point of contention raising challenges about the sovereignty of future systems. The argument used by a state that another state's sponsored company could make future systems insecure, or at least vulnerable to outages, has of course huge impact on trust of the technology as a core infrastructure for society and enterprises. It may be that a in future projects, and research support strategies, we need a proactive policy of ensuring that we can ensure the European manufacturing and provisioning of future network equipment.

1.3. CELTIC-NEXT's Vision

1.3.1. Vision's narrative

As we implement and exploit the successive generations of the communication infrastructure, we see that each new set of technical capabilities stimulates an exciting new set of services and, correspondingly, a new set of opportunities for vertical sectors to enhance their offerings and operations through the paradigm shift of full digitisation of the European industries and society.

The CELTIC-NEXT vision is to accelerate the full digitization of the vertical sectors through a strong collaboration between the ICT technology communities and the vertical industries. In the context of the CELTIC-NEXT "end-to-end" approach, projects will be encouraged to address the full value chain to comprehensively integrate the technological and business enablers to ensure a significant return on the Eureka European and associated nations' research investments and to gain a competitive edge for their respective industries.

The vision of the future communications is the ongoing digitalization and automation of many aspects of our lives — the automation of everything. This shift is driven by the current enabling technology trends like cloud-based services with dynamic and adaptive scaling, extensive virtualization, novel software-defined automated solutions and wireless connectivity with the 5G mobile networks. We will move from an era defined by the connection of people and simple things by Mbps of capacity and ~100ms latency to one defined by Gbps of capacity and ~1 ms of latency. This is characterized by 360-degree video, virtual and augmented reality, as well as autonomous system control with associated cognitive systems that augment human intelligence. All this will demand a fundamentally different, distributed network architecture comprised of cloud processing resources, interconnected by optimized IP and optical edge networks, and this with a converged ultrahigh capacity broadband access layer. The edge cloud network will need to support data rates of 10 Gbps, latency as low as 1ms, and a trillion connected devices with 10+ years of battery life.

CELTIC-NEXT, as a Cluster in the EUREKA cluster program, will also promote and support the Eureka ethos of "business knows best" and we give our community the freedom to create their ideal consortia and to decide on the technological focus of their international R&D projects. The unique value of the clusters is, by negotiation, to help align the business interests with the national ambitions in the Eureka program.

CELTIC-NEXT encourages the ICT community to reach out to the vertical sectors to collaborate on an international and industry-driven R&D projects that cover the whole value chain. All types of players from large companies to SMEs, universities, research institutes and even end users can participate. The Eureka cluster system assists international collaborative projects to access national funding and lets small organisations work in partnership with major industry players on close-to-market projects that generate not only products, but future collaborative eco-systems where the collaborations go long beyond the projects.

CELTIC-NEXT is based on the core values that have been supporting the Celtic community for 18 years, i.e., a bottom-up industry-driven approach, along with large "flagship" projects aimed at solving issues of strategic importance through a combined effort and coordinated approach of public authorities and industry. CELTIC-NEXT will continually look at improving the processes and tools in a similar manner as in Celtic-Plus so that they timely match the evolving demands of the overall landscape. It will also refine periodically its scope and orientations, to further strengthen the initiative. Increasing the flexibility of the programme to cope with the quicker pace of technological and market developments, as well as allowing projects that are closer to the market, up to high technology readiness levels, will increase the impact of the projects and of the programme on economy and society. Providing the opportunity for students and researchers to contribute with innovative ideas shall remain a key asset of the CELTIC-NEXT community.

1.3.2. Main Technological Scope

1.3.2.1. Narrative

The main technological scope and focus of CELTIC-NEXT is in the domain of ICT technologies but these are now becoming an integral part of all digitised business models across the vertical industry sectors. Societal and governmental applications and services also have to be available to citizens anywhere and anytime. This requires that a pervasive high-performance reliable and secure communications infrastructure be developed, implemented, and provided in a cost-effective way to support the future business, societal and governmental life. Social aspects such as e-inclusion must also be considered to ensure all members of society can enjoy the benefits of these advanced communications capabilities.

CELTIC-NEXT is a key tool in the development of the next generations of enabling telecommunications technologies and services, that will reflect the evolving needs of businesses in all sectors and citizens in Europe and beyond, for a broad range of applications and solutions, in an increasingly digital society. It plays a very important role in bridging the gap between the long-term focussed research programmes, such as the European framework programmes, and the shorter-term needs of European industry. The essential innovation needed to take emerging technologies from being emerging technical concepts to becoming exploitable products in the market is the domain of CELTIC-NEXT initiatives

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Cybersecurity is a fundamental element for the Digital Transformation of the Digital Single Market aiming at both protecting the European citizens, enterprises, infrastructures, or institutions against cyber-risks as well as developing the cybersecurity sector competitiveness. It applies in remarkably diverse environment such as Cyber Physical Systems, 5G & Beyond (thus cloud), social networks, web-based applications.

Mastering the creation of value from Big Data will be a cornerstone in the future economic development and societal well-being. To achieve that goal CELTIC-NEXT will work on Big Data challenges and pave the way to strengthen all parts of the "data value chain" so that a Big Data value ecosystem and data-powered innovative business models can evolve. That includes people and organizations involved in data whatever their role, be it producing, analysing, using, or creating value from data.

Concerning **Artificial Intelligence** (AI), key research targets include learning with fewer examples, the application of learning methods to dynamic systems, the capability to explain AI decisions, the combination of AI with model-based optimization, the development of machine learning methods coping with distributed data sources and computing processors.

The development of AI and **Big Data** is one more incentive for users and consumers to **take better control of one's Digital Life** in the forthcoming years. Concretely it means that users will need to be accompanied in their usage and in their need of transparency and control of the digital tools. The future digital platforms and tools will need to strike the right balance between empowering and assisting the users versus giving them the control and the choice. Privacy issues will need to be taken care of, not only but especially in the eHealth domain.

CELTIC-NEXT will work on the research challenges in the **e-Health** and **e-Care** sector, such as high reliability and guaranteed Quality of Service; high security, privacy and authentication; Scalability to high number of users, as well as ease of use for non-ICT specialists.

Besides eHealth, another vertical is related to **Smart Cities**. Considering the continuous fast growth of wireless Internet usage and the emerging new smart city applications such as smart traffic control, smart lighting (including the LED technology), self-driving cars and air quality monitoring, the smart city infrastructure will take into account the disruptions from digitalization towards the higher level of automatization and from the related new business models. A digital ecosystem of a future smart city will improve safety, energy efficiency, air quality, effectivity of transportation, and quality of living. "Breaking up the silos" is essential to leverage smart city opportunities. CELTIC-NEXT will help defining an open and interoperable urban platform reference architecture, forming a system of system approach. To achieve that goal and open interfaces are a prerequisite, allowing new ways of interaction between different industries.

The digital infrastructure of transportation in a city should merge all physical transport assets in a single and easily accessible platform using all smart city technological enablers such as big data, IoT and 5G to provide novel services to the integrated transport system such as new business models, new transportation models and social innovations. Such **Smart Transport** platforms can form a basis of multimodal travel planners, transportation networks, mobility services, transport on demand services, tracking and tracing activities.

The services provided by the digitization and integration of transportation platforms can benefit from crowdsourcing based real-time user and vehicle information to enable a faster, comfortable and controllable experience to users leading to a fully personalized services and offers.

It is important that the different actors of the value chain cooperate in order to invest the best **Connected and Autonomous Vehicles (CAV)**: car manufacturers, OEM, electronic equipment manufacturers, IT and telecom companies and mobile operators.

Linked to the CELTIC-NEXT vision of Smart Cities our vision of the **Smart Home** foresees users being offered a seamless and consistent experience when interacting with products and services bridging home, on the move and integration with smart city infrastructure. The future smart home should benefit from an open ecosystem allowing third party services to be integrated with the different Smart Home elements with AI-driven service improvements and cross-service possibilities.

Smart Agriculture as well as the whole agri-food sector will benefit in the coming years of the deployment of massive number of connected objects. Traceability will be enabled by IoT platforms, empowering agri-food sector and allowing traceability of food information for consumers. The Digital platforms for e-Agriculture and smart manufacturing should finally use common enablers for optimization purposes. In response to ecological and budgetary issues, new consumption patterns are emerging. **Personalisation and Quality of experience** will be key trends, not only in ICT but also in all industry sectors. New ways for production will meet those new consumption ways. **Smart manufacturing** often referred as 4th industrial revolution will transform the traditional business of manufacturing of goods towards service-based business in global value chains.

Digital Enterprises complement the smart manufacturing processes: Digitalization will develop at each stage of the lifecycles of the products and services from development to deployment, from purchasing to services, from manufacturing to logistics covering all the vertical processes that an enterprise has, generating value all across the stakeholders (customers, suppliers, shareholders, value chain partners, third parties etc.)

In the next years we expect a convergence of learning and work in the Enterprises. Personalized digital learning environments will help reducing skills gaps and will therefore have a very important positive impact on economy and social innovation for society. **Digital Education** will benefit of emerging technologies like artificial intelligence, big data analysis and machine learning, virtual reality, augmented reality, speech recognition, conversational interfaces, drones, robotics, and 3D printing.

In the **media, entertainment and gaming areas**, media will become immersive and highly interactive to provide ambient media consumption at home but also on the move. There will be a big focus in coming years on mixed reality. Interactive technologies such as Augmented (AR) and Virtual Reality (VR) are set to transform the ways in which people communicate, interact, and share information on the internet and beyond. Besides new 5G capabilities will enable Ultra High-Fidelity media and live event coverage. Content production will diversify, there will be both user and machine generated content, as well as cooperative content production.

Gaming will expand into a full immersive multi-sensorial environment. Collaborative gaming will expand while game development may also become more cooperative with users directly interacting with the developers in real time. New gaming technologies will take gamification to all business lines and industry sectors.

Sustainability and energy efficiency will get a similar range, spanning from telecom networks and services to the whole industry, transports, smart buildings, smart cities, and smart agriculture. Sensors will be used to measure and take counter actions when needed. New technologies should be used to prevent, measure, and communicate pollution information. New applications should exploit data for climate, and anonymized health data to warn and avoid damages at a bigger scale. Artificial intelligence with machine and deep learning may also help reduce the energy consumption.

CELTIC-NEXT should in particular deal with **Smart Transport** (landside, sea and air…). Future projects may define the digital infrastructure of smart transportation, merging all physical transport assets in a single and easily accessible platform using all technological enablers such as big data, IoT and 5G. The ultimate goal is to provide novel services to the integrated transport system such as new business models, new transportation models and social innovations. The CELTIC-NEXT framework will invite different actors of the value chain to cooperate in order to invest in the best-connected **transportation systems including autonomous vehicles**: car manufacturers, OEM, electronic equipment manufacturers, IT and telecom companies and mobile operators.

The ever-changing network: Even if 2018-2020 has seen the first 5G Release(s) being experimented with and commercial deployment starting, 5G is still an evolving technology. 5G is still at the centre of the CELTIC-NEXT technologies as some major features like end-to-end slicing, high accuracy positioning support, Time Sensitive Networks (TSN) and non-3GPP and non-terrestrial 5G convergence are still under development.

The work on moving **beyond 5G** and **preparing for 6G** are also at the heart of CELTIC-NEXT technological ambitions. It is expected that many of the current projects testing the capabilities of 5G will generate requirements to determine what 6G will be. Some major research initiatives on 6G are emerging in the long-term and academic programmes and these will start to spill over into the business scope of European industries within the next 4 year period.

Quantum technologies like Quantum Key Distribution and its use to secure the network management type communications over the physical optical layer, including wireless communications, are part of the strategic technologies that CELTIC NEXT supports. In fact, all aspects of "Quantum" communications will be also supported where they can enhance the security and viability of advanced applications and services.

Network supported **Geo-location Technologies** allowing both outdoor and indoor precise location tracking / positioning services will be essential for higher level targets like smarter and more efficient supply chains, automated traffic management and driving in the future. Interconnection of ICT platforms (like 3GPP CORE) with wider scope geolocation platforms will bring a lot of innovations forward in the next upcoming years. Also combining RATs with those platforms will enable a step change in spectrum management and optimization of radio resources. Privacy is a factor here too.

While, starting with 5G Release 16 &17, 3GPP technologies will enhance positioning precision provided by satellites, the SATCOM community and the 3GPP community have entered a deeper cooperation era, looking at more roles for Satellites in the 5G and 6G networks; not anymore frozen in its role of Mobile Backhaul and Location positioning, SATs will start to support so called NTN (Non-Terrestrial Networks) for 3GPP technologies, possibly providing direct 5G and 6G access capacities (LEOs and HAPS) to end devices, but also embedding Core Networks and MEC computing capabilities, opening largely the field of applications, from type of services to locations. Combining different satellite types together, or creating multimodal satellites (SATCOM, GPS & Observation), will also make the services offer explode.

The **future network architecture** will also change in line with the strategy of moving services to the edge as more and more low-latency, high volume data, services will be requested by users. To deliver these, various network resources need to be moved to the edge or far edge of the combined ICT infrastructure. The volatile nature of these services over time and optimisation of the location will demand a stronger virtualization and programmability of the ICT resources.

Automated and Autonomous network management and operations technologies will be required to oversee and manage the future networks given the incredible density of network elements, both physical and software defined, that will need to be continually tuned and optimised. The issues of Spectrum management as we implement private and public 5G networks in the same physical context and even the high density of pico cells in the 5G roll out scenarios will require advanced management tools. AI management capabilities may be needed as the scenarios get too complex for human management.

Finally, new markets may open to ICT players, such as **future financial and Fintech services** which have great potentials for a growing shift in the revenue pools of the operators and ICT players especially concerning the digitalization of lending payments and investment, online P2P (person to person) money transfer, e-wallet usages, changing customer relations with online/mobile transactions and customized financial solutions and digitalization in insurance. ICT players as newcomers in the financial business should bring impressive solutions and services, achieving the desired, efficient, optimized and secure Fintech platforms established on the needs of the citizens, governments and the actors of the technology and market value chains.

1.3.2.2. Synthetic technologic scope

All sus-mentioned envisioned use cases and application fields will rely on the following categories of enablers and larger families of technologic research and development axes that constitutes the ICT technology vision of CELTIC for the coming years (this vision spreads over more than a MAP timeslot, MAP periods being subsequent phases for the development of this vision).

The higher level of the technologic scope resides in identified fields of services that ICT technologies will have to fully support and even foster for the future:

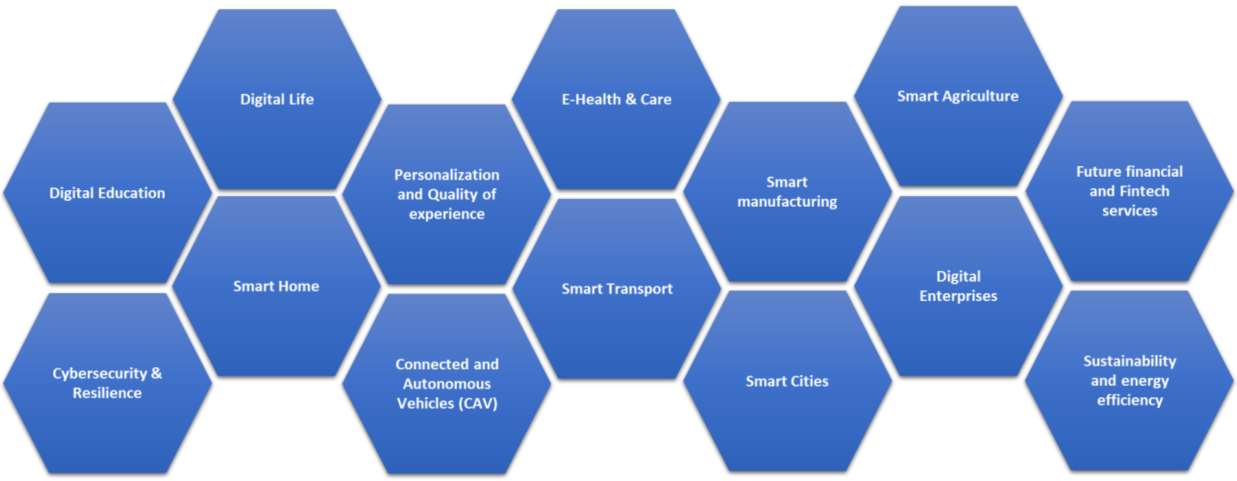

Figure 2 : Identified fields of services that ICT technologies must fully support

The next level of technologic scope resides in the identified enablers to those services:

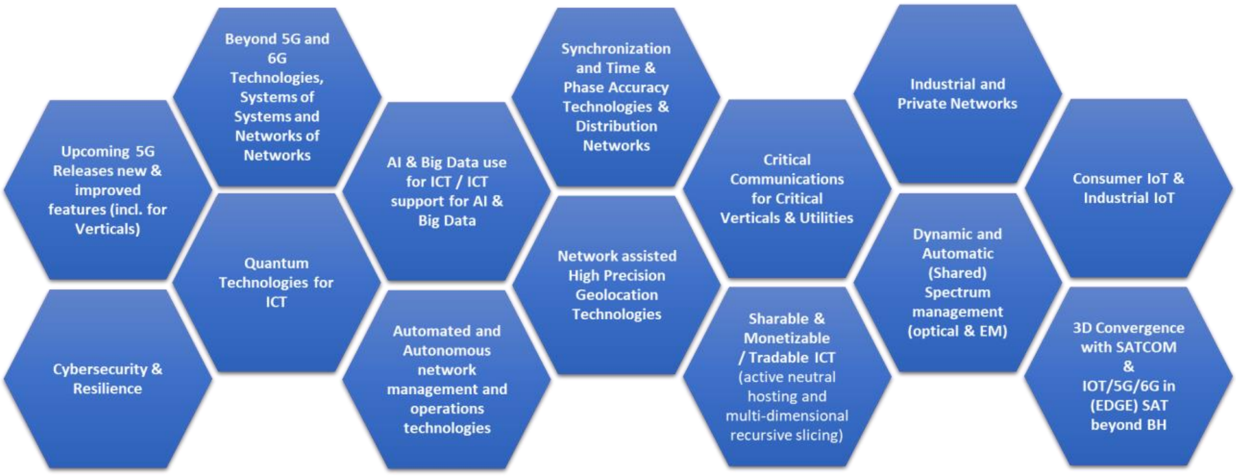

Figure 3 : Identified ICT enablers to Vertical Services

All those enablers need to be assembled and organized as systems of systems and deployed as networks of networks to support the above fields of applications and services.

A more detailed breakdown of those categories is provided in the Strategic Roadmap section (4) of this document.

1.3.3. Targeted Impacts of the CELTIC-NEXT programme

CELTIC NEXT activities are expected to generate returns on the investment in several major fields:

Industrial Return on Investment impacts

- Retain and develop Europe's and individual European Nations' competitive edge in telecommunications,
- Strengthen Europe's and individual nations' vertical industries,
- Unleash open and joint innovation opportunities in a bottom-up way, and in larger flagship projects, and finally at inter-clusters level.

Economic Return on Investment impacts

- Business aspects - European countries and champions' share in the global market,
- Unleash economic opportunities between European nations, and with Eureka partner countries.

Social Return on Investment impacts

- Support Green Deal objectives,
- Enable the achievement of UN SDGs (Sustainable Development Goals) via ICT solutions,
- Cater for social inclusiveness and create high value jobs,
- National Security via Cyber projects at national level while coherent with EC rules and programs.

Political Return on Investment for Public Authorities

- Trust from their citizens,
- Taxpayers' taxes invested in projects providing demonstrable Social and Economic Return on Investment,
- Target digital autonomy, national and European sovereignty,
- Helping in EC level decision making by showing national investment and results.

Standardization Bodies impacts

- Contributions to standards (future, mid-term),
- Faster time to market for latest standards releases (present, short term).

Regulatory Bodies impacts

- Inform National Regulatory Bodies and Agencies with project-based data and return of experience,
- Bring industrial communities and national regulatory communities closer together to develop joint understanding of applicability of technologies and regulations.

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2. CELTIC-NEXT Strategic roadmap (3-5 year)

2.1. CELTIC-NEXT: Main Research Topics and Challenges (Narrative & topical)

This chapter outlines topical and important research subjects and challenges in the ICT and Telecommunication area that form the strategic roadmap for CELTIC-NEXT for the next period.

This section is an updated extract from the CELTIC-NEXT – Scope and Research Areas document, first published in 2018 and now available via the CELTIC-NEXT website. This online document will be updated once CELTIC-NEXT gets confirmation of its renewed operation approval through the ECP process.

The lists of items in the following sub-sections are not comprehensive. Following the "bottom-up" approach of CELTIC-NEXT, proposers are free to propose projects on any subjects, as long as they are related to ICT and Telecommunication.

2.1.1. Communicate and Share

The fundamental driver to transform the communications network architecture and functionality for the vision of the future is the ongoing digitisation and automation of many aspects of our lives — from communication and content to compelling human shared experiences and the control of any physical system and infrastructure — what we will call **the automation of everything**. This shift is driven by current enabling technology trends like cloud-based services with dynamic, adaptive scaling, extensive virtualisation, novel software-defined automated solutions and ever-increasing wireless connectivity with a great promise of 5G and **will require a redefinition of networking concepts and a new digital infrastructure involving radical shifts in technologies, architectures and business models to meet future digital needs.**

We will move from a regime defined by Mbps of capacity and ~100ms latency – an era defined by the connection of people and simple things, to one defined by Gbps of capacity and less than ~1ms of latency, characterised by 360 degree video, virtual and augmented reality, autonomous system control, with associated cognitive systems that augment human intelligence.

The era of automation of everything will demand a fundamentally different, distributed network architecture comprised of cloud processing resources, interconnected by optimised IP and optical edge networks, with a converged ultra-high-capacity broadband access layer. These elements will be coherently formed and reformed into a converged, cognitive, and cloud-optimised network. The edge cloud network will need to support data rates of 10Gbps, latency as low as 1ms, and a trillion connected devices with 10+ years of battery life.

This will lead to a new era of industrial value creation across a broad range of sectors including healthcare, manufacturing, energy, agriculture, transportation, mining, etc. leading to a potential economic impact in the range of $4 trillion to $11 trillion per year by 2025.

Overall trends and requirements

<u>**Almost infinite capacity**</u>

Network capacity is one of the key drivers for the network architecture evolution with respect to continuously growing data and video traffic. However, this massive demand increase comes at a time when network technologies are reaching physical limits, which are hard or even impossible to overcome with conventional architectures and technologies.

Spectrum resources in lower frequency bands (<6GHz) are almost exhausted and spectral efficiency is approaching the Shannon limit as digital signal processing technologies have improved significantly over the past decades**. As a result, spatial density is the only dimension with sufficient potential for further significant capacity growth.** In essence, this means that network dimensions must get smaller, allowing significantly higher spectrum reuse per spatial area. Both fixed and wireless access networks will have to reduce their reach to ~100m to scale density by at least 10x and provide per-user data rates of 10Gbps. In the wireless domain, these shorter distances open up new frequency bands above 6GHz, which have much shorter propagation reach. In the low band, beamforming enabled by massive antenna arrays can also be used to increase spectral efficiency, providing additional capacity gain over conventional systems.

Means for spectrum sharing and co-existence like spectrum pooling and automatic spectrum allocation based on agreed policies will improve spectrum exploitation, which ensure access, availability, and reliability as well as QoS requirements of different spectrum owners and services**.**

The capacity problem in the access domain can mainly be solved by moving the physical layer termination close to the end user to open new frequency bands, and by wireless beamforming to increase spectral efficiency.

Imperceptible latency

Human communication and entertainment services using audio, video, email, or text messaging, or information retrieval from web services and applications, are currently the dominant applications running over the network. Human perception is on the order of 100ms for such services. Augmented, Virtual and Mixed Reality services will enable physical interaction of humans with virtual and remote real-world objects.

In addition, mass deployment of video cameras, connected sensors and actuators enables the development of mission-critical cyber-physical systems for the automation of manufacturing processes, large-scale traffic coordination of autonomous vehicles and logistics, and adaptive precision control systems such as remote surgery. Optimal operation of these machine-machine systems requires cloud-based supervision (for more complex decision making) combined with semi-autonomous local control (for simple/well-defined decisions), which in turn requires reliable connectivity latencies as low as 1ms. This requires the distance to the service to be less than 100 km.

Current wireless technologies, together with centralised cloud architectures support latencies on the order of 30-100ms, sufficient for a satisfactory Quality of Experience (QoE) for human communication and information retrieval. New services require a 10-100 x improvement in latency. Notably, achieving this latency requires optimisation of every link in the network, including optimisation of the radio interface, and streamlining RAN and core processing.

Tera scale things

We anticipate that a trillion IoT devices and sensors will be attached to the physical world and stream data that will allow our world to be continuously understood, adapted, and remotely controlled to meet emerging needs and significantly improve productivity.

The total cost of deploying, connecting, and operating this tera scale of IoT devices needs to be disruptively low to be economically sustainable. For long-lived, simple sensory devices for remote applications, battery life is a major determinant of operational cost. Thus, there is the need for 10-year battery life to match the typical device service life and allow ‘deploy (or drop) and forget’ deployment and operation. This requires highly optimised wireless communication for short data bursts with minimal signalling and control overhead.

With the growing IoT space the variability in the needs of devices is increasing as well as the number of applications demanding orders of magnitude higher daily data consumption and processing capacity of this big data.

Cognitive operations

The dynamic, distributed networks and associated systems and platforms, and the data generated by the tera scale things will result in an unprecedented level of complexity that is beyond the ability for humans to process. The degree of network and service control will manifestly increase, with the advent of so-called network slicing to provide the flexibility for an operator to support the rapid deployment of new services with well-defined and often critical requirements (latency, bandwidth, availability, reliability, security). In addition, personalisation of services by contextualisation of each solution to match user expectations will also increase transactional complexity. These evolutions require an increase in network-based intelligence, to both monitor and optimise service experience.

The continuation of Moore’s Law with new transistor designs, 3D stacking with silicon photonics and optical interconnects, GPU (Graphical Processor Unit) architectures supporting advanced matrix/parallel computation, the continued revolution in neural networking methods and advanced machine learning, and possibly neuromorphic chips and quantum computing paradigms, will support to handle the complexity.

Perpetual protection

Scalable, contextualised, and automated security, privacy will go well beyond current solutions, which is driven by:

- The increasing number of data breaches triggered by the increasing value of digital data.
- The low risk and high potential gain from 'ransomware' attacks.
- The expanding threat surface due to a move from billions of smart devices to trillions of simple things that will be connected to the internet.
- The future potential for disrupting industrial and infrastructure systems via network-based automation and cognitive operation systems.

The resulting security and data integrity and privacy impact will be enormous as attacks will affect human-interface devices and relatively simple IoT devices that can be activated or deactivated en masse, by compromising their control systems, or be converted to billions of bots propagating attacks. Mission-critical networks will increasingly be targets for attacks.

Future network architecture

Addressing the digital needs will require significant changes in network architecture and technology. Nine architectural dimensions are identified to ripe for disruption, forming the pillars of an end-to-end convergent network architecture.

Massive-scale access

Future network capacity and traffic density needs can only be met by a massive spectrum expansion combined with a significantly higher access node density, and a major increase in spectral efficiency for each link and carrier deployed. Spectrum expansion will occur by selectively tapping into centimetre and millimetre wave frequency bands and leveraging additional, often shared, spectrum in the sub-6 GHz range. Carrier aggregation techniques ensure that end-users can seamlessly exploit all available spectrum resources. Access node density will rise through cell splitting in macro deployments as well as a substantial increase in small cells for public and industrial usage, ensuring coverage for high data rate services.

Massive antenna arrays (massive MIMO) will be essential enablers of ultra-capacity networks by improving spectral efficiency through spatial multiplexing gains, thus providing higher data rates for more users and with extended data rate coverage.

Sub-millisecond latency is feasible based on an appropriate radio interface numerology and frame structure including variable scheduling intervals with a resolution down to fractions of a millisecond. Persistent priority scheduling will ensure predictable queueing and extremely short delays for critical low-latency flows. End-end latency starts to be limited by the speed of light in transport and backhaul networks, which implies that low-latency applications must be hosted in distributed edge clouds closer to the end user devices.

Other dimensions of the future systems are extending operation into long range operation for broad coverage of narrowband IoT applications and the reduction of energy consumption especially for IoT applications. Sleep modes are an efficient means especially when networks operate at low average load.

With fibre reaching to or close to all end users, non-fibre, 'last-100 m' extensions will enable high-capacity access over existing copper, coax and mmWave wireless systems. As all these technologies approach capacities of 10 Gbps and beyond, they will use similar signalling processing capabilities to minimise impairments, maximise signal-noise ratios, and bring fibre-like speed to next generation non-fibre DSL (Digital Subscriber Line – XG-Fast), cable (XG-Cable) and wireless (mmWave) access.

Converged edge cloud

Telecommunication networks and cloud infrastructures are currently based on centralised architectures where traffic is transported to small numbers of core nodes and datacentres hosting services and applications. While this model is suitable for mobile internet services and reduced operator's TCO (Total Cost of Ownership), it has limitations in terms of low latency applications requiring round trip times below 10ms. It is also subject to bottlenecks in transporting large traffic volumes to those core locations.

The emerging architecture features are distributed to small-scale datacentres at the network edge, located at the convergence point between access/aggregation and metro core networks, or in some cases dedicated clouds are pushed all the way to the industrial location (e.g., advanced AR/VR, ultra-high resolution content delivery, critical IoT, automation, robotics, and control systems). To support applications and services that require the lowest possible latency, key edge/core functions of the network must be distributed differently. Network functions will be decomposed by separating control from data plane functions to enable independent scaling and flexible placement in a distributed architecture. Data plane functions will be more distributed, while control plane functions can typically remain centralised.

Smart network fabric

The 'smart' network fabric will dynamically interconnect new converged network edge clouds and core clouds, large cloud providers, global CDNs (Contend Delivery Network) and the internet. It will also connect high-density enterprise locations and wireless cell sites, alongside the software defined PON (Passive Optical Network), cable and DSL access systems.

As the functions of the network are virtualised, and the functional nodes of the network become a mesh of edge clouds and core clouds, the primary role of IP/optical networks becomes cloud interconnection. To ensure both efficiency and reliability, the scaling and placement of all cloud network workloads must be dynamic. This creates a unified cloud infrastructure dynamically distributed over a mesh of locations — driving correspondingly dynamic traffic patterns.

Scalability and programmable flexibility will be critical for the optical layer providing the raw transport capacity spanning the network, because traffic patterns become more dynamic due to on-demand services and shifting cloud workloads.

Flexible optics with tuneable wavelengths, variable modulation formats and levels, and variable spectral-width channels will enable optimisation of the information rate vs. distance vs. spectrum used. This enables to dynamically adapt to changing traffic patterns and network degradations. Taking advantage of all this to optimise the network requires a comprehensive network view of topology, resources, traffic, and utilisation, as well as programmatic control over these flexible resources.

The optical layer also must continue to scale massively. This includes raw system capacity, and supported interface rates when interconnecting large routers. Current systems are fully exploiting amplitude, phase and polarisation of light but are approaching the non-linear Shannon Limit of spectral efficiency. Thus, further large gains require leveraging the two remaining dimensions: frequency and space.

Given limits to digital signal process speeds for advanced higher-order modulations, scaling the transmission rate per wavelength to Tb/s and beyond will require efficiently aggregating multiple parallel carriers on the same fibre. Long-term scalability will require spatial super-channels utilising parallel light paths (fibres and/or modes on a fibre).

Universal adaptive core

Enabling new business models as well as the need for extreme operational agility and automation require a fundamentally different cloud-native core network which is based on the following architecture principles:

- Radical simplification by separating orthogonal functions — session management, access/mobility management and user plane are independent network functions. User and control plane have been split to enable distributed user plane deployments for latency-critical applications hosted in edge clouds.
- A service-based architecture allows for rapid creation of new services. Network functions will expose their capabilities as 'services' that can be consumed by any other network or application function, enabling flexible per-service software deployment.

Programmable Network Operating System

Virtualisation and software-definition of network assets, whether for connectivity or network functions, are the key components of a programmable network. The critical control and management that intelligently orchestrates these assets and makes them available programmatically for both internal and external needs, is the programmable network OS, which forms fundamental enablers together with virtualised assets for:

- Capex efficiency, through flexible and dynamic assignment and reassignment of assets to current needs.
- Operational efficiency, through automated speed and agility of assembling and operating virtual building blocks.
- Growth, through on-demand virtual connectivity and NaaS services.

Network slicing

The concept of network slicing is enabled by the programmability and automation of the network OS. Network slicing is a key capability underlying new business model opportunities. Operators will be able to provide dedicated virtual networks to various customer groups much more economically than in the traditional model where these customers would build their own dedicated private networks. Network slicing gives operators the flexibility to dynamically instantiate and run multiple network instances (slices) on the same physical network infrastructure. A network slice is an independent, virtualised e2e network, which, from a customer or business partner perspective, is behaving in the same way as a dedicated private physical network, including business logic and network management.

Augmented cognition systems

Comprehensive and efficient network automation is especially important for operating highly disaggregated and virtualised production service environments with massive numbers of dynamic endpoints and connections. These needs for automated service instantiation, agile scaling and live function migration, threat detection and remediation, auto resiliency, and more apply not only to network operators, but also extend to the programmable NaaS consumers and their virtual networks, such as MVNOs, global enterprises, verticals undergoing their own industrial automation transformations, and the digital value platforms discussed.

While automated service instantiation is handled primarily by the network OS, reacting proactively in time when complex arrays of resources need to be adjusted to prevent demand, failure, and security events from impairing QoE requires application-awareness, deep insight into application flow demand and performance, and advanced predictive analytics capable of triggering network actions. The analytics and machine-learning at the core of the cognitive cloud work in concert to enable automation of the three operational dimensions of elastic capacity, cognitive security, and autonomic reliability — coordinated through an overarching orchestrator utilising a common policy engine.

Digital value platforms

Digital value platforms will provide global virtualised enterprises with the ability to scale with worldwide demand and yet leverage local infrastructures and resources to deliver their digital goods and services with unmatched user experience. Likewise, it will provide industrial, agricultural, healthcare, and other verticals more agile and efficient ways to produce and deliver their physical goods and services. The automation and programmability of everything will permeate and transform virtually all industries.

Dynamic data security

The future network architecture introduces a new paradigm for dynamic data security which is based on two pillars: the systematic automation of multi-layer security mechanisms orchestrated across the e2e network, and the creation of a digital trust framework architected to ensure data and system integrity, visibility, and regulatory compliance in a highly dynamic and multi-entity environment.

Network-wide automation of security is needed to cope with the scale and sophistication of future threats including advanced ransomware and APTs (Advanced Persistent Threat). Digital trust mechanisms need to offer for example the verification and audit of data, processes, decisions and rules that are driving the workflows and the dynamic behaviour of digital automation systems such as the control of autonomous cars and robots.

Pushing cognitive security agents to the edge of the network supports most effective scaling and defends against threats and attacks as close as possible to the source.

ICT networks in Space

Satellites already provide critical services to ground and airborne communication services. They can provide GPS (location and time) information to other networks and they can provide backhaul capacity for remote locations not reachable (at reasonable cost) by terrestrial networks. The recent developments in the Satellite technologies, like MEOs, LEOs, open new opportunities for innovation in the integration of the satellites in the end-to-end ICT networks.

The new scenario is where 5G/B5G/6G evolutions will explore new areas of joint development such as the installation of 5G access radio nodes directly in the LEO satellites and it will evolve to a larger initiative to use the SAT as platform for network services, like Core networks, VAS, (Space) Edge Computing services, along with the more traditional simple IP transport capabilities (with increased data rates available). The challenge to the Satellite community is to make the satellite as flexible and configurable a “Network Asset” as the various elements for the 5G and beyond infrastructure will be. We need to be able to include satellite communications in a sector specific "slice" configuration form.

New integrations with avionics will be also enabled, like air-to-ground, air to air, air to space, where airplanes and High-Altitude Pseudo Satellites (drones & balloons), will also become part of the connectivity grid. Similarly, sea vessels and maritime fix nodes (like offshore wind farms and petrol platforms) will also play a role in the future connectivity pervasiveness across the Globe.

An interesting opportunity for combining SAT with ICT and verticals could be to explore how SAT data issued from embedded earth observation systems and SAT networking information to derive some AI/ML based actions for verticals like for road management, logistics, natural catastrophe prevention but moreover management and recovery.

ICT Infrastructure as the key Critical Infrastructure Utility

Today, energy, water, and transportation infrastructures, known as "utilities", are considered critical infrastructures by governments and the populations in general. The utilities all have their own roadmaps for modernization and additional services many of which are based on using advanced ICT technologies for all their functions through maintenance to exploitation, including a certain level of automation.

There will be an evolution for these utilities using dedicated private isolated networks to being able to use designated "slices" in the public networks, thereby benefiting from the pervasive, reliable, secure of the future networks and reducing their Capital investments. 5G will address many of the vertical sectors' needs to the extent where wireless capabilities will be able to support the critical infrastructures and, in some cases, replace their fixed network investments.

The inevitable trend that will emerge here is that Connectivity is fast becoming a Critical Utility in itself. This means that not only will the future infrastructure have to offer Full Real End-to-End Slicing, enabling Multi-layered multi-tenancy, full neutral hosting, multi-Dimensions sliceable (incl. Space, Spectrum and Time) with high availability and reliability guarantees, but it will also have to employ state of the art capabilities, such as Artificial Intelligence(AI) and Machine Learning(ML) as part of the management and operation tolls to ensure the network can deliver to all customers at all times.

The intelligence in future systems will also enable a new dynamic in the way networks will be able to self-adapt or re-configure to follow changing needs, like with large groups of people going to or from major events, or adapting services in response to severe events like COVID-19, or having "self-healing" capabilities following major catastrophes or climate events.

Major research challenges

Major future research challenges are expected in the following areas:

- Exploration and exploitation of centimetre and millimetre wave frequency bands.
- Massive antenna arrays and use of carrier aggregation techniques across available frequency bands.
- Means for spectrum sharing and co-existence.
- Low latency requires: New network architecture with edge clouds close to the end user and centralised clouds with flexible function split and optimisation of radio interface, RAN and core processing.
- Use of network analytics, big data and artificial intelligence/machine-learning, neural networks and quantum computing to enable complex network control, management and automation, as well as intend-based networking.
- New security mechanisms as part of the overall system design from the start.
- Broad deployment of software technology for efficient and secure implementation.
- Optimisation of network protocols beyond the today's Internet protocol to meet new requirements.
- Optical communication: Scalability and programmable flexibility of optical links, tuneable wavelength, variable modulation schemes, approaching limits in optical transmission by exploiting all dimensions amplitude, phase, polarisation of light, frequency, and space.
- Feasibility study and deployment blueprints for emerging transport technologies, such as Radio-over-Ethernet, transport-sensitive networking and FlexE
- Energy efficient devices, systems, and protocols.
- Chip architecture design and implementation for high processing power.

- 5G xHaul solutions (front-, mid- and backhaul) for various 5G RAN functional splits and support of slicing capabilities, for stand-alone 5G deployment and multiple non-stand-alone scenarios.
- Implementation of open-source pieces for software and hardware components
- New technologies to monitor the performance of next generation networks (5G and beyond, SDN-NFV, optical networks, etc.)
- New techniques to determine and improve the user experience to assure a satisfactory Quality of Experience (QoE)

2.1.2. Building trust

Cybersecurity is a fundamental element for the Digital Transformation of the Digital Single Market aiming at both protecting the European citizens, enterprises, infrastructures, or institutions against cyber-risks as well as developing the cybersecurity sector competitiveness. European cybersecurity should be considered as specific as it must respect European values. As a direct consequence digital autonomy deserves trustworthy cooperation between academics, industry, and public agencies.

Considering digitalization of the B2C/B2B/B2G, common major trends drive Cybersecurity through transformation to comply with the new ICT picture:

- Convergence of ICT and OT (Operational Technologies) is becoming a reality and requires engagement of Verticals (Public Safety, Health, energy, transport, banking, industry 4.0,) potentially with Mission Critical constraints or even operator of essential interest.
- Emergence of the IoT leading to new issues in terms of vulnerabilities, authentication, and scalability. Both for mass market and Industrial applications.
- Continuing Cloud evolution with Service-based architecture and “XaaS” (Everything as a Service) paradigm
- 5G and beyond 5G infrastructures and services coming with predominant software and virtualization usage.
- Identity and Access Management challenges in extraordinarily complex Cyber Physical Systems
- Data life cycle with privacy and confidentiality enforcement in a competing world of Big Data and Artificial Intelligence
- Need of Evaluation, Certification and Exposure of Cybersecurity properties/attributes for complex systems and Services End-to-End aggregation.
- …more and more numerous and sophisticated cyber-attacks

Digital Transformation must come together with cybersecurity transformation.

Developing Efficient Protection Solutions

Protection “by design”, “by default”, “by orchestration” remain a cornerstone of cybersecurity but must evolve to comply with systems and services. It applies in remarkably diverse environment such as Cyber Physical Systems, 5G & Beyond (thus cloud), social networks, web-based applications.

There is some needs to develop further the following topics:

- Data Protection, all along its life cycle, including GDPR application. At rest, on the move but also as sharing is required, Solutions allowing multi-party computation with privacy and confidentiality respect. This may include cryptographic technologies and/or anonymization technologies.
- Safe Code assurance and life cycle from source code analysis towards control of update/upgrade phases
- Cyber Physical architectures with Security enforcement
- Hardware and embedded secured platforms
- Software Defined Security for security function deployment
- Software Defined Security for innovative strategies (micro segmentation, deception, …)
- Software Defined Security using autonomic (self*) technologies: Detecting misconfigurations and vulnerabilities so that corrective actions can occur to assure policy compliance and risk reduction.
- Continuous Security assessment of systems and Services including configuration of the termination points/devices attached to a network.
- Security as a Service, including Identity and Access Management for users/devices.
- Security Policies consistency and conformity. From edition towards formal proof.
- Privacy preserving mechanisms.
- Authentication in complex IoT and Cyber Physical Systems

- 5G slicing Security.
- Liabilities and forensic in 5G systems and services
- Security properties/attributes exposure, Service composition and user awareness
- Evaluation, certification, and trust
- Post quantum cryptography

Use of artificial intelligence and blockchain in cybersecurity.

Artificial intelligence and blockchain are promising technologies expected to play a major role in the ICT domain. Blockchain is defined as a digital, decentralized ledger that keeps a history of all transactions made over a peer-to-peer network.

Blockchain is revolutionizing many transaction-based industries. At the beginning, in focus were mainly financial services. However, applicability & further technology developments go far beyond the financial area. Blockchain was, at the beginning, viewed mainly in connection with Bitcoin. Broadly speaking, Bitcoin is a scheme designed to facilitate the transfer of value between parties.

Unlike traditional payment systems, which transfer funds, denominated in sovereign currencies, Bitcoin has its own metric for value. Bitcoin is a complex scheme, and its implementation involves a combination of cryptography, distributed algorithms, and incentive driven behaviour. Due to the creation of Ethereum project & smart contracts, the applicability areas of blockchain technology are growing fast.

Corporations and start-ups explore functionality of distributed ledger technologies, defining use cases with broad applicability, from public to industrial and private applications. The technology is believed to have the potential to transform almost all industries. Anywhere value is created, where trust and security are concerns, one can think of a potential application of the blockchain related technologies. Just as the World Wide Web created an “internet of information”, blockchain can be seen as the fundament of the “internet of value”. Thus, business potential together with applicability areas focusing on use cases, are relevant for many actors of the ICT value chain.

Developing efficient detection and remediation solutions

Attacks are also subject to innovations and cybersecurity must run this race with two main categories: known attacks and patterns and “zero days”.

- Artificial intelligence application for attack patterns learning.
- Artificial intelligence application for attack patterns correlation over complex systems and third parties
- Software Defined Security: smart probes deployment
- Algorithms for self-adaptation and reconfiguration against attacks IoT weakness mitigation by Policy Enforcement distribution (Gateways, diodes, …) in the architecture
- Deception strategies
- Response to incident coordination (data models, protocols, …)

2.1.3. Artificial Intelligence and Big Data

Big Data

In recent years, there is an explosion in the size of data being generated all over the world and there are numerous possibilities in several areas to further collect data. Data are only meaningful if they can be analysed to produce new improved products and services in all domains including science. Big Data and Artificial Intelligence are key enablers in storage, retrieval, and analysis of data. Currently there are big implementations by technology giants, but smaller scale implementations are just starting to become mature. Therefore, those important technologies will provide big opportunities.

New products and services using Artificial Intelligence and Big Data will change the way people will live and work. There will be a big market for development, sales and service of enablers for Big Data and Artificial Intelligence ranging from hardware, software, repair services to technical /management consultancy in these areas. The products themselves will be another big market. As companies and governments start to deploy related technologies, all organizations will need to follow to stay competitive.

New data and new algorithms using the data will provide many new or improved products or services to people. A good example already being developed is the self-driving car. Analysis that could not be done in the past due to lack of data or processing power will now be performed with new technologies. Consequently, Data and Artificial Intelligence will reveal unknown relations and pave the way to new advancements in science and technology. All these factors together will lead to a big market and big advancement in science and technology with widespread use of these technologies we also expect new social and legal implications.

Big Data is a key economic asset to achieve competitiveness, growth, and jobs due to its potential for impact and as an enabler for both horizontal and sector-specific gains. For instance, Big Data and all information collected by the medical staff can help doctors make the right choices more quickly. A smart use of Big Data can help in managing traffic flows and in making our cities smarter. Big Data enables the timely and appropriate delivery of products for consumers and efficient processes for business.

Mastering the creation of value from Big Data will be a cornerstone in the future economic development and societal well-being. Europe should better exploit Big Data potential in the coming years. To achieve that goal, we need to strengthen all parts of the "data value chain" so that a Big Data value ecosystem and data-powered innovative business models can evolve. That includes people and organizations involved in data whatever their role, be it producing, analysing, using, or creating value from data.

CELTIC-NEXT will work on Big Data challenge:

- Volume: Which data should be stored? For how long?
- Velocity: how to react to the flood of information in the time required by the applications
- Data discovery and relevance: how to find high-quality data from the vast amount of data available?
- Variety: how to handle multiplicity of types, sources, and formats?
- Data ownership: who owns the data?
- Privacy: Can we extract enough information to help people without compromising their privacy?
- security, governance, and ethical issues.

Artificial Intelligence

Artificial Intelligence has a long history, starting in the 1950's with the Turing Test and gaining recent momentum since the early 2000's with technological breakthroughs (e.g., Deep Learning), large investments as well as broad mass market applications (e.g. Apple's Siri, Amazon´s Alexa, etc.). Today a variety of technologies bring AI to life, such as computer vision, machine learning, natural language processing and some more. Already in 2016 50% of the internet traffic was generated by bots, as well as 23% of the twitter accounts.

Artificial Intelligence is defined as the imitation of human intelligence/intellectual processes by machines, especially computer systems. These processes include learning, reasoning, and self-correction. Particular dimensions of AI include machine learning and expert systems.

Machine Learning: Machine Learning mainly deals with pattern recognition and the automation of algorithms to enable computer systems to learn from huge amounts of data. Supervised Machine Learning is used for prediction and classification and unsupervised Machine Learning for clustering.

- Deep Learning
- Statistical machine learning
- Artificial neural networks
- Expert Systems: Programs which are designed to support specific tasks (in areas for monotonous and rule-based tasks), by following complex algorithms.
- Automation (e.g., Manufacturing)
- Recommendation Engines (e.g., Financial Dec. Making)
- Diagnosis, Troubleshooting

"Intelligent Machines"

Cognitive capabilities enable machines to become "intelligent":

- Reasoning: In information technology, a reasoning system is a software system that generates conclusions from available knowledge using logical techniques such as deduction and induction.

- Perception: The capability of a computer system to interpret data in a manner that is similar to the way humans use their senses to relate to the world around them. Hardware and software have allowed taking sensory input in a way like humans.
- Planning: Branch of AI that concerns the realization of strategies or prediction of action sequences, typically for execution by intelligent agents, autonomous robots and unmanned vehicles. Planning is also related to decision theory.
- Extended cognitive capabilities
- Communication: Focus on interactions between computers and human (natural) languages. Challenges like language understanding, gesture or emotion recognition exist to enable computers to derive meaning from human or language input.
- Knowledge Representation: Focus on information representation in a form that a computer system can utilize to solve complex tasks such as diagnosing a medical condition or having a dialog in a natural language.
- Generalized Intelligence: The intelligence of a machine that could successfully perform any intellectual task or the ability of a machine to perform general intelligent action that a human being can.

Future AI use cases for ICT and industry

Artificial Intelligence technologies hold tremendous potential to improve and automate many aspects across the Telco value chain, ranging from:

- Network planning and automation
- Infrastructure performance
- Infrastructure security
- Innovative services (B2B and B2C)
- Smart human computer interactions (natural language understanding and generation; visual voice and multimodal recognition; conversational agents
- Sales (Sales agent support systems),
- Products (Recommendation systems, smart hubs),
- Customer service (automated CRM)
- Internal processes (Online marketing optimization, financial forecast automation, etc.)

The increasing use of AI and machine learning technologies turn the converged and cloud-optimized network architecture into a cognitive system. AI enables a higher degree of automation and adaptability of the infrastructure, allows to cope with the increasing complexity of networks and systems, and helps human operators by providing assistance and insights on complex matters.

Some specific use case examples are the following:

- Contextual service creation and management tailored to user needs Fault management, proactive maintenance.
- Cybersecurity threats identification and remediation
- Prediction of resource requirements to guarantee the quality of experience and associated proactive network/computing/storage resource allocation and orchestration on virtualized, programmable infrastructures Optimization of physical layers performance (coding, interferences, handovers...)

Besides, AI will have uses cases in smart industry, digital enterprise, digital education, smart cities and smart transport, autonomous cars and fintech.

Rigorous research and open and transparent dialogue with the experts from industry and academia networks, will multiply the potential of Artificial Intelligence in the coming years and allow the commercialization of valuable solutions for industry and end-users.

In this context CELTIC-NEXT ecosystem will do research and development of best practices, Proof-of-concepts (PoC) and Minimum Viable Products (MVP) within relevant areas of the telecommunication value chain and beyond.

Next research challenges of Artificial Intelligence

- One important limitation is the necessity of huge, labelled data sets to train AI systems. For some topics, these labelled data are easily accessible (pictures of cats, pictures of faces, audio signals and their textual transcription, etc). But for more specific domains such as networks, expert knowledge is expensive for training. Consequently, learning with fewer examples is still a key research target for AI.

- A telecommunication network is more and more a highly dynamic system, application of learning methods to such non static system is a challenge.
- it is difficult to understand "what is learnt, why, and how". There is no explanatory power to these classification or interpolation techniques, i.e. they cannot explain the reasons of their response, the concepts or logical relations that they have discovered. Therefore, the capability to explain AI decision is a research topic for the coming years.
- It is very difficult to design hybrid methods that combine known models of phenomena (like physical models, equations, etc) with Neural network-based learning methods. Combination of AI with model-based optimisation should be investigated as it has the potential to bring further relevance, efficiency and performances in the digital infrastructure automation and optimisation.
- Information and data are massively distributed within the cloud and on the Internet of Objects. In this context developing distributed machine learning methods coping with distributed data sources and computing processors is a key innovation topic. Exploiting massive parallelism, intelligent distribution of processing between edge clouds and core clouds, and efficient scheduling of the training phase of AI apps during off peak hours are some of the approaches that need exploration and solutions.

2.1.4. Protect the Planet and Assure a Sustainable Future for Human Society

The threats over our planet are more and more numerous. The environmental crisis is enlarging from nature to food and health. Because of the continual increase of greenhouse gas, the climate change is getting faster and threatening our water resources, food safety, and ecosystems. Pollution of air, water, soils, and noise pollution are increasing sanitary risks.

The world energy consumption is expected to increase of 48% between 2016 and 2040, whereas some critical resources (like rare earth metals…) may lack at some point.

As taxes against carbon dioxide will appear in more and more countries and increase in value new technologies should be used to prevent, measure, and communicate pollution information. New applications should exploit data for climate, and anonymized health data to warn and avoid damages at a bigger scale.

The citizens, governments and firms are getting more and more aware of the need to protect against pollution, recycle resources and use renewable energies. National and international regulations will push companies and customers to more efficient use of resources in production modes and towards the generalization of recycling. In the next 8 years we will see the transition between a logic that is still close to intensive industry production to a logic of eco-conception while ways to bypass resistance to change should be invented.

New technologies and solutions should answer all those environmental challenges. Frugal innovation may also inspire the conception of new ways, equipment's, services, and applications.

Energy efficiency will be a key word not only for telecom networks and services but also for the whole industry, transports, smart buildings, smart cities, and smart agriculture. Sensors will be used to measure and take counter actions. Among the previsions the world market of smart agriculture should reach 11 Billion USD in 2022 (with a Compound Annual Growth Rate (CAGR) between 2017 and 2022 of +13,2%)

These constraints will have impact on the production and recycling of telecom and IT devices and networks (use of substitution materials, intermediation, waste management, conception of devices that have more autonomy or event that are energy self-sufficient.

Telecom and IT networks will need to be more and more energy efficient, using new tools for predicting and managing their traffic loads. At service level the environmental footprint of digital usages will be more and more monitored to reduce it as much as possible while preserving the quality of experience.

As responsible equipment sourcing will be of utmost importance, this will foster eco conception:

- "from cradle to cradle" concept (already 85% of the waste from electronic devices should be collected and recycled from 2019 onward),
- innovative modular designs for hardware (e.g., for networks of antennas) and software,
- telecom and IT equipment using renewable energies.

New technologies will be developed to store energy (domestic batteries, …) and to get energy back, and smart and micro grids will develop even more. (The CAGR of smart grid between 2016 and 2021 is expected to be +27%).

Solutions for energy management in homes, offices and industries will be enhanced and interconnected with remote management control. Energy efficiency labels should develop.

Artificial intelligence with machine and deep learning may also help reduce the energy consumption.

At service and application level we should also imagine innovative tools for social regulation of consumption. Innovative services should ease and develop the circular economy, and eco-responsible consumption modes. Collaborative consumption (sharing instead of owning) help reduce the impact of human activity on the planet. It is expected to be multiplied by 10 in 10 years to reach a world market of 302 Billion Euros in 2025.

Finally, **Satellites are becoming more and more important in the ICT field and for Global Sustainability** as they provide observation capabilities both at global Earth level and at very granular scale. Combining observation, geolocation and improved ICT capabilities will provide a great field of joint exploration to achieve national and global sustainability goals. CELTIC-NEXT has already engaged deep conversations with both ESA and the Portuguese Public Authorities (new Eureka Chairmanship) to create a powerful collaboration between those Stakeholders.

2.1.5. Foster Health and Wellness

The World Health Organization (WHO) defines eHealth as "the cost-effective and secure use of ICT in support of the health and health-related fields including healthcare, health surveillance and health education, knowledge and research."

The spread of eHealth applications will help reducing the cost and the societal burden of Healthcare in Europe, with needs that are likely to grow further over the next decades. Thanks to the growing penetration of smartphones M-health is expected to potentially cut costs of healthcare by 15% and increase the effectiveness and efficiency of the delivery of care.

People will in the future have multiple sensors and actuators placed on their body and around it. Those things will synchronize with the phone and give an active person an overview of the workout statistics, elderly person an outlook of the body condition, or a diabetic the sugar levels. These things may also communicate with the city infrastructure providing statistics on the most popular running tracks or health conditions of people in different neighbourhoods, for instance. When somebody has a degraded health condition, or if there is a health emergency, doctors will be able to use body sensors and smartphone camera to remotely diagnose the patient and – if needed – send help much faster.

Key topics in the health domain now are the real time integration of a massive number of "things" (IoT), processing of large amount of data (Big Data), the integration of data on the fly from different sources and across different networks, and aggregation of services across different domains to support integrated care models.

This is a wide area from the ICT perspective, including, e.g., the interoperability of computer-based medical systems, management of electronic patient record, and the interconnection of hospitals and medical team remotely. 5G is seen as a key enabler for large-scale adoption of eHealth services.

CELTIC-NEXT will work on the research challenges in the eHealth sector, such as:

- High reliability and guaranteed Quality of Service
- High security, privacy, and authentication
- Scalability to high number of users
- Ease of use for non-ICT specialists

2.1.6. New ways for Consumption and Production

New consumption ways

In response to ecological and budgetary issues, new consumption patterns are emerging. Individuals are more and more looking towards sustainable, economical, and ethical consumption. Those different aspects are considered before the buying decision. Thanks to information available on internet consumers compare and optimize their buying acts.

Do It Yourself, Local and collaborative consumption (e.g., car sharing) as well as circular economy are expected to develop further. New business models will adapt to new consumption modes, for instance "pay on use" is expected to develop in the coming years thanks to available data from IoT platforms.

Digital tools facilitate the communication between the brands and the consumers in both ways. Consumers are developing toward *"Consumactors"*. Social networks will have a growing role in future consumption modes through ratings and recommendations.

In parallel manufacturers are getting more knowledge about the customer needs, usages and preferences and therefore will be able to offer more and more personalized products and services, in real time, according to the context and even the emotions of the client. Brands are developing new strategies to engage their clients via personalization or gamification.

Industry 4.0

There are several significant trends in modern manufacturing, every one of them dependent heavily on the advances in digitalization. Firstly, manufacturing occurs in company networks or ecosystems. A factory is typically linked upstream to many subcontractors or suppliers serving the factory with components, subsystems, raw materials, etc. Digitizing or automating a factory itself is a tremendous challenge but as manufacturing has been distributed to the supply chain it creates the need for connecting such smart actors seamlessly together and thus enabling a holistic connectivity across the value chain. Connecting a factory in downstream, i.e., to customers, integrators, or retail, is becoming increasingly significant as "servitization" of manufactured goods or customer support are becoming important, as well as many kinds of feedback to manufacturing or to R&D. Secondly, from product point of view, the so-called digital twin is increasingly important from early product idea through high value-added product design, assembly or manufacturing, and operative use. Such product lifecycle stages need to be seamlessly connected through respective digital twins.

The use of digital platforms is increasing heavily, both from company network or ecosystem point-of-view (operative technologies) and from product life-cycle point-of-view. One significant trend is that operative functionalities are being outsourced and offered remotely via cloud. This trend has started in condition monitoring, etc., but in the course of increased high-speed communication, far more operative tasks can be potentially implemented or provided via internet or cloud, even most time-critical control-loops or alarm signals. Even though such all-in-the cloud concepts may become technically possible, it is foreseen that many kinds of cloud-edge architectures emerge. It may not become feasible or rationale to broadcast back and forth huge amount of data across continents, or subjected to communication breaks, security threats, etc. Autonomy within edge remains preferred, whereas certain functions remain in clouds.

Increased complexity of products and production, more agile business cycles, many kinds of time, safety, and quality criticalities, moving to lot-size-one or tailored products with mass-production efficiencies, human-system interaction or user experience multiply the requirements for software systems as such, as well as communication speed, latency, and reliability.

The landscape and contexts of digital manufacturing are significantly governed by Industry 4.0 in Europe and Industrial Internet Consortium (IIC) in America. They both build on top of 3G or 4G technologies but also need very essential higher-level connectivity, interfaces, interoperability, standards, and tools.

Implementation Issues:

Connectivity by 5G for Internet of Things: The forthcoming 5G mobile network will provide many service capabilities and features essential for the digital manufacturing of the future. It provides Internet of Things (IoT) wireless connectivity to the sensors, control, and operations & maintenance systems of the factory machines. The wireless connectivity will enable flexible re-placement of the machines and other systems within the factory for a dynamic manufacturing environment. The ultra-high reliability and ultra-low latency of the 5G connectivity will enable joint innovations of the wireless and the digital manufacturing for even the most critical applications.

Cloud: Cloud computing and high-speed connections enable centralized processing of data in distance from the manufacturing sites. However, the privacy and protection of the data, ultra-low latency response times of some factory applications, such as robots' control, will require local edge cloud computing at the factory site. In addition, ultra-high reliability requirements will require edge cloud computing. There will be need for innovations for such distributed network architectures. The innovations on the digital manufacturing and digitalization of the value chain can build onto this cloud computing platform, complemented with the 5G wireless connectivity platform.

Big Data Analytics: Data yielded from sensors within and around the machinery and the products themselves will create feedback loops. In a manufacturing environment, big data can be used on large quantities of produced data to uncover trends, and useful insights, that can later then be relayed for use under human intervention. Furthermore, this data may be linked with artificial intelligence and machine learning, to be able to drive towards a more automated factory floor.

Automation and robotics: The use of robots in manufacturing will increase even more in the future. They will enable automation of production, and even in increasingly complex and precise processes. Wireless IoT connectivity by 5G will open the possibilities for innovation on the monitoring and control of robots. In particular, robots for extremely precise tasks will require innovations on the extremely low latency communications paths between the robots and the control functions.

Additive manufacturing: As consumers desire for increasingly customised products, designs become too, increasingly complex. However, assuming there is no increase in the amount of material used, there is no additional cost on a 3d-printable design because the manufacturing technique is additive rather than subtractive, i. e. there is no material base to cut or erode from. This enables the production of tailored products on a more cost-effective and scalable basis. Together with lower costs of 3D printers and increased functionality enabling manufacturing companies to leverage them on a more industrial scale than at present (where use cases are typically limited to prototyping / research and development), 3D printers will become a mainstay in the manufacturing environment.

Metrology technologies: Metrology technologies are evolving rapidly, with technologies based on quantum physics promising results unattainable by measurements taken in a classical framework. In a factory, solutions shifting from the off-line paradigm, where the product must be taken from the production line to be inspected, towards an in-line model, where the product is inspected whilst still on the production line, will lead to a more automated digital factory, requiring even a lesser degree of disruption to the production line.

2.1.7. Smart Cities and Smart Territories

Ongoing climate change, global and local demographic changes, waste, and lack of natural resources in conjunction with the hunger for a comfortable life require action in various dimensions. Since most humans do already or will live in cities, cities become the focus of action due to their rising importance and sheer size, e.g., in 2025 around 40% of Japan's population of around 105 million, will live in the area of the capital Tokyo.

The role of the cities as living environments will continue to increase for migration of the population to the large cities and thereby a critical mass for new service paradigms based on digitalization.

To address increasing urbanization and provide a good quality of life, e.g., provide a functioning supply, requires innovation often coupled with technology, e.g., the Internet of things. This process of modern urbanization is currently seen as becoming a "Smart City" whatever it means depending on the role, interests and needs of the different actors in a city or region.

The leaders of the cities are becoming increasingly aware of the need to design the fast transformation of infrastructures, processes, and landscape in a holistic, multi-disciplinary and sustainable manner. A successful city needs to continuously develop its attractiveness and efficiency while navigating through the complexities of urban digitalization. This can be seen as the international race toward the "smartest city".

Ultimately, the city councils and their operations centres will have a full sensor-based visibility to all necessary parts of the city operations as well as real-time control allowing optimization of them.

Many cities have already applied integrated and holistic approaches on the design of the city infrastructures but one important component – telecommunications - has still been largely ignored. The radio base stations, the visible part of the telecommunications networks, often emerge as an incremental add-on without coordination between the competing mobile operators. Considering the continuous fast growth of wireless Internet usage and the emerging new smart city applications such as smart traffic control, smart lighting (including the LED technology), self-driving cars and air quality monitoring, the infrastructure for a smart city must evolve with well-planned steps, taking into account the disruptions from digitalization towards the higher level of automatization and from the related new business models.

To manage the uncertainties of the steps and fast innovation on the smart city applications, the cities need to secure the availability of the underlying infrastructure at the right spots, especially electricity and telecommunications for the future smart city digital ecosystems.

Our society and cities face great challenges to improve safety, energy efficiency, air quality, effectivity of transportation, and quality of living. A digital ecosystem of a future smart city will enable:

- Development of a new smart city infrastructure and digital services
- Improvement in maintenance of the city infrastructures
- Improved data capacity for the applications and services for the citizens
- New services and business opportunities for the companies
- Opportunities for new types of micro-operators in the value chains

Communications networks - the nervous system for a digital smart city

The capacity of the mobile networks must grow significantly to enable the digital smart city services of the future for the increasing number of the users. The services will be connected with the users through a reliable high-capacity wireless network on a very high frequency and deployed in very small cells. The high frequencies above 6 GHz of the 5G mobile system will be required for the steeply growing data traffic in the smart cities due to the surveillance cameras, 3D-streaming and other high bandwidth services. The radio signals on a very high frequency travel only short distances and therefore a high number of small radio cells with a distance of 50 meters will be deployed. This can only be achieved in a city environment in an economic way by using the street light poles as the platform for the 5G small cell base stations and multiple sensors. This kind of infrastructure of the light poles, electricity and data transport form a platform for the 5G radio network and a variety of sensors. The platform is economically viable only as a solution with one 5G base station and one set of sensors per pole which is provided by the city as the public authority. It is then shared by the mobile network operators as the sensor data and transfer platform of the digital smart city eco-systems. The citizens will benefit from the new smart city services based on the open data shared in the eco-systems and utilized by the providers of services & applications.

The implementation of a smart city will require innovations on the new types of street light poles onto which the 5G radio equipment, wireless backhaul, video cameras, as well as the air quality, weather and location sensors can be attached to, and of course the intelligent LED streetlights on the top. The 5G networks will provide the common, flexible and total cost optimized high-capacity communications network for the smart cities. All the data transferred from the smart light pole platform is connected to the open 5G computing nodes at the edge of the network, potentially also partly placed inside the poles. The computing nodes make the data from the sensors available to the eco-system of service providers for their innovative applications serving the citizens of the city.

Research areas

- Novel business models on the ownership and sharing of the infrastructure will need to be applied.
- Since different domains use in many cases their own protocols and data formats, the need for further investigation on suitable meta-data formats is important.
- The new GDPR laws on data privacy require additional efforts, e.g., the deletion of all data tracks if individuals upon request.
- The 5G networks on the street level will require innovative solutions and versatile service platforms utilizing the 5G technology This also implies the connection and investigation of interdependencies of an open urban platform and 5G slicing concepts.
- The impact and growing request for low-latency data and upcoming artificial intelligence show the need for further investigation.

2.1.8. Smart Transport

One of the most significant services in Smart City platforms is the integrated smart transportation and assistance services for citizens. In a poll organized at the Smart(er) Cities conference session in Mobile World Congress 2018, nearly 70% of the attendees have noted that smart transportation is the most significant service expected from a smart city.

Smart and fast transportation is even more crucial for large and complex cities. The digital infrastructure of transportation in a city should merge all physical transport assets in a single and easily accessible platform using all smart city technological enablers such as big data, IoT and 5G to provide novel services to the integrated transport system such as new business models, new transportation models and social innovations. Such digital platforms can form a basis of multimodal travel planners, transportation networks, mobility services, transport on demand services, tracking and tracing activities.

The services provided by the digitization and integration of transportation platforms can benefit from crowdsourcing based real-time user and vehicle information to enable a faster, comfortable, and controllable experience to users leading to a fully personalized services and offers. This model in transportation requires users to be involved in the system actively, requires a strong impact on users and ensuring all stakeholders to be able to benefit from the services provided by the platform to its full extent.

Connected and autonomous cars

Connected vehicles already exist and will develop further toward autonomous cars. Different connectivity types are needed: Vehicle to Infrastructure (V2I) and Vehicle to Vehicle (V2V). Inside the car a wireless LAN allow passengers to share the connectivity and enjoy infotainment services.

The connected car is expected to offer innovative services not only to the conductor and to the passengers, but also to many stakeholders: car owner, cities, territories, insurance companies, car manufacturer, garages, etc. The connected car may be coupled with Augmented Reality: Passengers would get information about their environment, projected on the windscreen.

There is a strong need for Cybersecurity to minimize the risk of cyberattacks both on cars and on infrastructure. Without cybersecurity autonomous cars will not be able to develop. AI will allow the connected cars to learn by themselves how to take the best decisions but also to adapt to their owner, conductor, or passengers. To cohabit with classical vehicles, autonomous cars will need a high level of embarked Intelligence from the very beginning, using for instance machine learning.

Therefore, it is important that the different actors of the value chain cooperate to invest the best connected and autonomous vehicles: car manufacturers, OEM, electronic equipment manufacturers, IT and telecom companies, mobile operators…

2.1.9. Smart Energy

One of the main tracks in providing a smart city is providing digitalized facilities to have more control on energy consumption and to provide a more sustainable energy supply. The smart energy concept covers all aspects in energy context, from production to consumption. Smart energy aims at greener energy generation, lower energy consumption, an energy consumption pattern with flattened peaks, and a resilient distribution grid.

The main objective in energy sector is the reduction of consumption to conserve natural and financial resources. This requires urban sustainability through the promotion of structural and coordinated actions with service providers. Big data analytics, Internet of things and communication infrastructures such as 5G are the main technologies to enable a fully monitored and more efficient energy cycle in a smart city.

Among the solutions to provide a more sustainable energy policy in a city is the replacement of street and public building lighting systems with more automated low power ones and the use of photoelectric and motion sensors to automatically turn the lights on and off and adjust their intensity according to the environment needs. In addition, centrally managed or automated approaches can be used in energy management facilities to manage the energy flow to energy grids and infrastructure.

Furthermore, the energy grids need to be smarter, to promote the rational use of electricity also on public roads, in homes, hospitals, public buildings, and industries. The consumption can be monitored using automated meter reading approaches based on Internet of things, that covers 3GPP technologies such as NB-IoT or LPWAN approaches such as LORA.

Lower energy consumption can be influenced in citizens using gamification based on the data extracted from consumption profile of citizens individually or as a group. Also, the more responsive devices should be adapted to daily life which can manage the energy consumption depending on the current total energy demand to reduce the peak levels in energy.

Microgrid and smart grid involvement and management in a smart city is crucial for sustainable energy policies. Anomaly detection is a must to avoid non-authorized energy consumption and resource accessibility. All these components may be locally or remotely managed which heavily relies on Big data analytics, edge computing and Internet of Things.

2.1.10. Smart Agriculture

Smart agriculture as well as the whole agri-food sector will benefit in the coming years of the deployment of a massive amount of connected objects. The Internet of things (sensors, cameras, connected scales, …) applied to smart agriculture will allow fine monitoring and collection of biophysical data (water, solar radiation, temperature, weights…) for healthy development of plants and animals as well as management of irrigation, fertilization and crops. The digital platforms for e-agriculture and smart manufacturing should finally use common enablers for optimization purposes: IoT platforms with reliable connectivity, Cloud computing, Big Data processing linked with AI and machine learning, standards API, automation and robotics.

The ultimate digital platform and connectivity networks in the smart agriculture area should allow the traceability of food in the production process all over from farms and vineyards to consumers. On the other way round some feedback communication loop about customer satisfaction and preferences will allow quality improvement of future agriculture production.

2.1.11. Smart Home and Smart Building

Today, a Smart Home consists of a series of fragmented vertical markets served by a complex integrated ecosystem of players and devices across multiple industries which is generating an exponential increase in the number of connected home devices:

- Comfort: thermostats, automations, lighting, remote control…
- Security: intrusion alarms, remote surveillance, presence simulation…
- Peace of mind: smoke or flood detectors, baby monitors…
- Energy efficiency: demand response, battery charge…
- Infotainment: TVs, STBs, OTT media applications…
- Health: remote monitoring, elderly care, quantified wellness…

With just a few exceptions, these vertical industries involve local or regional third parties, such as healthcare services, property insurance companies, private security, local commodities…

According to the level of ambition and the investment required to provision the service inside the home, there are two different types of Smart Home services: long term infrastructure investments and short-term user services.

Each household has different requirements and needs, different spending behaviours, and varying quality expectations. On average the number of connected devices at the home of a family of four persons has increased from 10 in 2010, to 25 in 2017 and is expected to be above 50 by 2022. Some market studies suggest that the connected home device shipments will grow at a CAGR of 67% to reach € 1.350 Mn by 2018.

The increasingly growing number and diversity of devices, together with the complexity of the deployment and the setting up of the connection, not only overwhelms most consumers (and sometimes even experts in the field), but pose huge security risks to consumer data and the safety of operator's infrastructures. Because of the inherent complex nature of these systems (uncontrolled, self-managed, varying qualities and quantities) it can be expected that only gradual steps towards a self-organizing smart home will happen soon. A service provider that takes responsibility for managing the quality, security and complexity of a smart home is costly but sometimes the only way to help consumers to live in a smart home.

Worldwide players race to achieve a position in the Smart Home market as the home centralized gateway: the key element that controls home life while juggling with all connected home devices and connectivity. Different industries are positioned differently in this race:

- Telco and pay-tv providers: already delivering home services with experience setting-up and managing CPE and home connectivity.
- Vertical service providers (e. g. remote healthcare) are pushing their devices at home, but most are limited to one vertical silo.
- Hardware manufacturers: able to deliver attractive consumer technology into homes.
- Digital players: who leverage on their size and agility to provide a standardized home operating system under their control.

But it can also be expected that in the future devices, appliances and services interoperate with each other. Today, most solutions are basically simple operations of "one device one service" offerings. There is basically no interaction between the different solutions and devices. This could change in a way that allowed devices to interoperate with each other, exchange capabilities, and consequently offer improved or new services to consumers.

The Smart Home ecosystem goes well beyond ICT industry, and the outcome of this race can deeply transform the related vertical services industries.

Smart Homes and Buildings form part of an extended vision of a Smart City. One possible such scenario is the integration at home of vertical features related to municipality services – in particular Smart City services – such as intelligent shared transportation systems or connection to public alarms. Another more complex scenario is the orchestration of the Smart Home energy efficiency policies with the grid supply or municipal efficiency strategy, where the Smart Building becomes relevant from the city point of view.

The CELTIC-NEXT vision of the Smart Home has four pillars:

- An open ecosystem allowing third party services to be integrated with the different Smart Home elements. In the coming years we expect AI-driven service improvements and cross-service possibilities.
- A smart central gateway, that ensures secure remote access to the Smart Home through user-friendly interfaces. Innovative chat-bots and voice assistants, acting as the main entry point will facilitate the control of the services, devices, and connectivity.
- Smart management of connectivity, including solutions that provide optimised Wi-Fi home coverage, increased network security, secure guest access…
- Management of vertical-specific devices that need to seamlessly connect to the home Wi-Fi with easy set-up and operation.

This vision links to the CELTIC-NEXT vision of Smart Cities, with users being offered a seamless and consistent experience when interacting with products and services bridging home, on the move and integration with smart city infrastructure.

2.1.12. Digital Enterprise and Digital Education

Digitalization in the enterprises is a living roadmap for the organizations since it is a continuing process that evolves with the changes in digital technology. Digital enterprises position digital technology in the core of their organizations which is in interaction; with the products and services they produce, with their customers they interact, with their business operations they process, with their strategic perspectives that they envision, with their professionals working inside and with the relationships with the ecosystem that they are in. The enterprises are more competitive, flexible, dynamic and efficient in their market value chains increasing their market values and stakeholder values by utilizing digital technologies. According to the Global Industry 4.0 Survey [1]; big gains are anticipated by industrial product companies in all regions, expecting gains over 20% in the next five years by additional revenue, lower costs and efficiency gains.

Regarding to the digitalization of the enterprises, the essential part of this transformation is the engagement of the professionals into the digitalization, forging their mindsets as technology centric which means a change in the culture of the company, placing speed, agility, automation into the system and having learning organizations with a high adherence to the digital education. The digitally transformed professionals digitalize processes of the vertical operations within the enterprises, influence the horizontal layers by working together with customers and suppliers within the digital ecosystem, introducing innovative and digital functioning products and services that are augmented by other digital interfaces. As the European actors play an important role in binding the companies and countries across Europe and beyond Europe, the parties of the ecosystem become more associated within the worldwide data networks and supply chains. In this aspect digital enterprise and digital education envisage the future of organizations globally with the acceleration initiated by the industrial leaders both influencing developed economies and emerging economies.

Digitalization and Integration of Vertical and Horizontal Value Chains

Digitalization exists within each stage of the lifecycles of the products and services from development to deployment, from purchasing to services, from manufacturing to logistics covering all the vertical processes that an enterprise has, generating value across the stakeholders (customers, suppliers, shareholders, value chain partners, third parties etc.) that are horizontally integrating to the enterprise. Digitalization of the enterprise embraces all the transformation and integration of these elements blending the data into real time, efficient, optimized, augmented and intelligent processes and operations.

Use of Data Analytics in Digital Transformation

Data analytics is the crucial capability in digital transformation of the enterprises both in digitizing the products and services and in creating new digitized products and services by interpreting the data flows coming from all of the resources. Advanced capabilities in data analytics generates outputs that lead for revenue boosts bringing competitive advantage. The usage of digital business models and analysis of the customer, transaction, access data creates value on existing portfolio and enriches the range. This leads to data driven services, offers, products, platforms and integrated solutions.

Ensuring Digital Trust with Data Integrity and Security

Digital Trust is the factor that digital enterprises cope with, in order to assure security and safety functioning over all the elements of the digital enterprise. The data communication, integration and storage should be complying with all the security requirements, harmonized to the regulations and to the intellectual property rights, building and protecting trust in the digitized era.

Digital Transformation of the Professionals

The vision of digitalization is determined and driven by the leaders of the organization, bringing in the digital culture and managing the transformation of the professionals. Changing the way of thinking and acting of the employees is crucial by supporting their motivation and improving their skills via learning, experimenting, implementing of the new technologies, collaborating with digital leaders in and outside of the organization. Precisely, digital education plays an important role for the professionals in gaining the required approach and capabilities in this new norm of future.

Coping with 21st Century Skills Gap Challenge in a Digital World

New technological trends like Industrial Internet of Things and Industry 4.0 powered by Artificial Intelligence (AI) are becoming important factors in transforming conventional business models and jobs. Machine Learning experts foresee that all jobs whose automation is possible will be replaced by software and robots in the not too distant future. In this new digital world, massive use of machine learning will impact the skills set of future human resources in a dramatic way. Today’s workforce, to a large extent, lacks the set of capabilities required by this new world and must therefore be developed very quickly.

Self-regulated Learning and Personal Learning Environments

Traditional instructional education means (Conventional Learning institutions, Learning Management Systems or MOOCS, etc.) and master – apprentice model is not enough for the enterprises and their human workforce anymore. There is a major skills gap between graduating students’ capabilities and industries’ expectations. In the meantime, it is a major challenge for enterprises and people to find relevant learning knowledge in an unstructured, scattered, distributed, and overwhelmingly large amount of big data ocean and un-learn / learn endlessly in this dynamic environment. Personal Learning Environments supported by emerging technologies like artificial intelligence, big data analysis and machine learning seem an effective solution for the skills gap problem. Addressing aforementioned skills gap issue will have a very important positive impact on economy and social innovation for society.

Convergence of Learning and Work in the Enterprises

Products and services provided by enterprises to their customers are in a constant change. Therefore, all employees of the organizations should continuously cope with the learning challenge of new and modified features of existing products, modified or expired marketing campaigns, brand new services and products, etc. In such a challenging environment, the learning problem of the teams cannot be solved solely by traditional in-class courses or coaching support anymore. Required knowledge including state of art in the world and best practices within the company should be fed to employees while they work in a personalized manner by using Artificial Intelligence methods and all the knowledge accumulated in the company.

How can Learning and Education field utilize Artificial Intelligence, Machine Learning and other emerging technologies?

Big data analysis, machine learning and artificial intelligence are two technologies which has a great potential for learning and education as described briefly in previous sections. Besides, virtual reality, augmented reality, drones, robotics, speech recognition, conversational interfaces and 3D printing etc. will have several applications in learning and education field.

2.1.13. Content, Entertainment and Gaming

Entertainment and gaming, including next generation of multimedia technologies, are undoubtedly considered as the uppermost important research technologies to be developed during the following years. Immersive experiences and gamification are a common place of the top trends for emerging technologies. Indeed, media and entertainment has been identified Most promising verticals for 5G [2]. In addition, the hyper-personalization of services around user and customer experience are embedded in the DNA of future generation of entertainment and gaming.

According to [3] Augmented reality (AR), virtual reality (VR) and mixed reality are changing the way that people perceive and interact with the digital world. Combined with conversational platforms, a fundamental shift in the user experience to an invisible and immersive experience will emerge. Over the next five years the focus will be on mixed reality, which is emerging as the immersive experience of choice, where the user interacts with digital and real-world objects while maintaining a presence in the physical world. Mixed reality exists along a spectrum and includes head-mounted displays (HMD) for AR or VR, as well as smartphone- and tablet-based AR.

Besides, immersive technologies are moving closer to the edge of artificial intelligence [4]. Over the next five years, enterprises will move closer to adopting immersive technologies such as augmented reality (AR), virtual reality (VR) and mixed reality (MR). These technologies will in turn force vendors to figure out how to get more artificial intelligence (AI) functionality out of the cloud and into the edge. When discussing immersive technologies, a fundamental point emerges: Both immersive technologies and AI are a collection of subset technologies. Tuong Nguyen, principal research analyst at Gartner, says businesses need to consider both immersive technologies and AI to be mutually beneficial. As AI improves, so do immersive technologies, and vice versa.

Regarding the potential between augmented reality (AR) and social media [5], when it comes to transparently immersive experiences, technology is introducing transparency between people, businesses, and things. As technology evolves to be more adaptive, contextual, and fluid, it will become more human-centric.

Interactive technologies such as Augmented (AR) and Virtual Reality (VR) are set to transform the ways in which people communicate, interact, and share information on the internet and beyond. This will directly impact a larger number of European industries ranging from the cultural and creative industries, manufacturing, robotic and healthcare to education, entertainment, and media, enabling new business opportunities. The challenge is to forge a competitive and sustainable ecosystem of European technology providers in interactive technologies. Better exploiting opportunities offered by multi-user interactions, researching, and developing technologies augmenting human interaction in groups within both professional and private contexts. Or developing future interactive systems offering higher quality experiences, for instance through systems which are mobile.

Moreover, Gaming will expand into a full immersive multi-sensorial environment which will result in a more realistic experience, improved ability for users to collaborate within the game and no limitation on the number of simultaneous users. Similar to other media areas, gaming is likely to move from a primarily “home based” experience towards an “anywhere” experience with user collaboration being both simultaneously in the physical world and the augmented reality domain, based on the user’s actual location. Game development may also become more cooperative with users directly interacting with the developers in real time.

In this line, the introduction of gamification has been unstoppable in recent years. However, it has gone unnoticed by many people. No doubt, gamification is present in such varied fields as learning, banking, energy, or health, but what is most important is that about 85% of activities in our lives will include aspects inherent to games by 2020 [6]. In other words, we are gradually witnessing the gamification of our life, the definitive game.

All in all, major future research challenges are expected in the following areas:

- New multimedia content technologies, such as Augmented reality (AR), Virtual Reality (VR)
- New gaming technologies to take gamification to all business lines and industry sectors.
- Artificial Intelligence and machine learning methods applied to multimedia and gaming.

- New hyper-personalized and collaborative services and applications that gather entertainment with social media.
- New technologies to monitor the performance of next generation networks (multimedia, entertainment, gaming, etc.)
- New techniques to determine and improve the user experience to assure a satisfactory Quality of Experience (QoE) AI/deep learning driven media content recommendation and personalization based on predictive behaviour prediction and advanced user profiles by continuous AI assisted user role modelling.
- AI/deep learning driven adaptive personalized media user interfaces, especially for TV and video, providing visual representation of content choice and discovery based on context and actual user preferences.
- AI supported service quality management for video quality.

2.1.14. Fintech: New Ways for Secure Financial Services

There is a need in the finance industry to support the creation of innovative tools and services in order to help the finance industry adapt to the challenges it currently faces. Robust yet agile and tailored financial services are essential for our economies, citizens, and enterprises.

Eit Digital [7] defines the needs for the three most important sectors for the finance industry: the retail banking sector, corporate banking services and the asset/wealth management sector.

The future of retail banking focuses on the way financial institutions will interact with their retail customers (i.e. our citizens) in the future, using modern digital devices and tools. A broad range of themes need to be supported, including cybersecurity, authentication, online payments, micropayments, cashless societies and personal financial management.

Modernised corporate banking is fundamentally important for the efficiency and productivity of European industries. Modern corporate banking services will help companies get more tailored access to the financial resources they need. The finance industry needs tools that help to create better financial transparency, automate and simplify financial and accounting tasks for companies, ensure fluid and secure lending, and improve financial services available to corporates, SMEs and start-ups in Europe.

In the Digitalised Wealth/Asset Management domain, technologies like machine learning and artificial intelligence algorithms are needed to provide better advice, structure better financial products, improve reporting, and support investment professionals in selecting the best financial products to withstand systemic risks.

Future financial services have great potentials for a growing shift in the revenue pools of the operators and ICT players. According to the prediction reports, in the year 2026 6% of all the 5G enabled digitalization revenues will come from financial services with 24 billion EURO. Significant new value generation opportunity for operators lie in digitalization of lending payments and investment, online P2P (person to person) money transfer, e-wallet usages, changing customer relations with online/mobile transactions and customized financial solutions and digitalization in insurance. [8]

The adoption of new ways for financial services is contingent upon inevitable secure solutions that are supplied tremendously within all the transactions. The numerous challenges may only be surpassed by the involvement of the states on a consensus, framing the main requirements of the fiscal measures and protecting the citizens that are needed to be compromised in European level and incompatible with world-wide spectrum.

Nevertheless, blockchain technology is one of the crucial instruments that provides a solution to digital trust because it records important information in a public space and does not allow the data to be removed in any way. The transparent, time-stamped, and decentralized features of blockchain enables the transactions to be recorded in a permanent scale without needing third-party authentication. [9]

We believe that fintech focused projects within the CELTIC-NEXT Community will support the European region and beyond, in regard to achieving the desired, efficient, optimized and secure fintech platforms established on the needs of the citizens, governments and the actors of the technology and market value chains bringing impressive solutions and services.

2.1.15. Help the users to keep control of their Digital Life

The digital life of citizens is organized around the smartphone and its applications. Apps represent 75% of the smartphone usage and allow the users to control their health, finance, home, purchases, education, entertainment, as well as their social life.

At the same time, social media are becoming more and more used - to the detriment of traditional media. Within a few years, social networks have become an essential communication means. Therefore, the control of one's digital image or e-reputation is gaining extreme importance. Not only individuals but also companies and organizations need to keep control of their e-reputation and digital communication, in particular, if, and, when, a crisis occurs. People are getting aware of being more and more monitored through their digital footprint and sometimes even eavesdropped. In the meanwhile, cyberattacks have been threatening billions of consumers. Some experts forecast that the average daily connection time, estimated today around 8 hours, could reach 16 hours in 2025.

In the forthcoming years users and consumers will need to be accompanied in their usage and in their need of transparency and control of the digital tools. The future digital platforms and tools will need to strike the right balance between empowering and assisting the users versus giving them the control and the choice.

Developing new digital tools and services will have to avoid the following risks:

- Exposing users and their data to cyber-threats
- Extreme monitoring that jeopardizes privacy
- Exploitation of unnoticed or unauthorized use of users' personal data
- Opacity of algorithms or data calculation resulting in biased information presented to customers.
- Artificial Intelligence algorithms fostering generalised measures without taking context and personalised factors into account.
- Blurring frontiers between reality, augmented and virtual reality and even pathological reality perception.

In the coming years we expect the development of secure and advanced multiservice digital platforms with messaging, e-commerce enablers (see WeChat messaging platform in China). The digital enablers will be enhanced, e.g., Chat-bots with advanced conversational systems including the automatic processing of natural language.

Digital coaches will be further developed to answer elaborated questions from the users and empower them in daily life and provide contextual services according to the personal usage. These digital coaches will come along with new tools to manage the personal data. They will develop into advanced smart digital assistant, able to reduce information overload (including protection against too invasive contents like certain ads) and to organize individuals' time, meetings, delegation processes, automate tasks, and even propose and guarantee the right to disconnect. Digital guardian angels are expected to be developed in the coming years to take care of each and everybody digital image as well as of the e-reputation of organizations.

New technical solutions will integrate "privacy by design". Digital tools and ICT networks will have to reflect the new European regulation on data privacy (General Data Protection Regulation GDPR). New tools will be developed to evaluate websites and services regarding the respect of personal data. Further to the European regulation, sophisticated mechanisms to allow data traceability (e.g., with a blockchain approach) and data portability should be made available. Localization data or health and financial records pose extremely important issues regarding privacy. To take care of cybersecurity issues there is a growing demand for encrypted communication services (such as messaging applications Telegram and Signal for voice and video) and for safe personal data storage.

A need for governance of algorithms is emerging. In the coming years, the transparency of existing algorithms will need to be evaluated whereas future algorithms should be designed taking the transparency constraint into account from the very beginning. Certifications or labels for algorithm transparency may be proposed.

2.2. CELTIC-NEXT: Main Research Topics and Challenges (Strategic Roadmap)

This chapter presents a strategic roadmap for the 3-5 upcoming years in line with the ECP MAP process. This strategic roadmap is derived from the Vision as stated in the previous section of this document. It supports the vision and gives greater detail on the technological scope for the next 3-5 years where the vision could be considered as showing the perspective over a longer period.

2.2.1. Future needs of the end users

A first step of the strategic roadmap is to consider the future needs of the end users. This is done here along two main axes:

1. The high-level application fields
2. The main technical areas of research

Once again it should be stressed that the guidance in this roadmap is indicative and the community may identify new key topics through the “bottom-up” approach that can equally add value to the evolution of the ICT services and applications domains.

2.2.1.1. High level application fields

This axis in the classification of user needs relates to applications and use cases that users will need to be provided with to enable them to benefit from the technology. They are mostly derived from known usages, bottlenecks, lacks, demands, emerging from the last years and quite specifically from the Covid-19 crisis.

Human Centred Technologies and Services, for an Augmented Life Experience

- Digital divide elimination
- Smart Regions/Cities/Buildings/Homes
- Smart Transportation
- Smart Tourism
- Sustainability & Efficiency of Smart Energy Grids
- Public Safety & Crowd Control
- E-Health & Care
- Users in Control and Trust of offered services
- Digital support for Education and Remote Education
- Digital (Media, Gaming, Sports, Culture and Entertainment)
- Remote working and Nomadic Working (Digital Nomads)

Full industrial digitization and support of vertical industries

- Digital Enterprises
- Private Networks for Smart Manufacturing (Indus. 4.0)
- Smart Logistics (geolocation IOT networks)
- Smart Agriculture
- Future Financial and Fin-Tech
- ICT support to third party AI based applications
- Connectivity Grid / Telecom Infra as 4th Utility, like Energy

Futuristic use cases

- Holographic “Teleportation”
- “World” Real-time Synchronous Digital Twin

Figure 4 : Future needs of the end users: High level application fields

2.2.1.2. Main technical areas of research to be supported by CELTIC-NEXT Cluster

This axis in the classification of user needs relates to main features shared among the previously listed applications and use cases. They are mostly derived from known usages, bottlenecks, lacks, demands, emerging from the last years and quite specifically from the Covid-19 crisis.

The main subcategories are:

Ubiquity / Pervasiveness	Dynamic capacity following people seamless mobility	Automation, Reliability, Transparency: Cognitive operations	Protection and Trust	Holographic “transportation” & Real-time Synchronous Digital Twin
•Urban, sub-urban down to rural •Into the home for education and remote working •One Identity for seamless experience •Smart Regions/Cities/Buildings/Homes	•In “normality” •In “crisis” (pandemics, major climate events) •Highly Precise Positioning •Edge Computing •Open-RAN / vRAN •Slicing	•Extensive Monitoring •Big Data Analytics •Artificial Intelligence •ICT supporting large and intense Ai/ML deployment for verticals (connectivity, processing, data storage…) •Transparency or the Imperceptible latency	•Cyber-security •Identity management	•Holographic media teleport •Multi-sense networks •Time engineered applications

Figure 5 : Future needs of the end users: Main technical areas of research

2.2.2. Candidate enabling technologies to be addressed.

Beyond 5G, from 5G to 6G	Wired and Wireless Industrial ICT	ICT Critical Infrastructure as a Utility, The Critical Connectivity Grid	Space dimension enabled 5G/B5G/6G	Distributed & Smarter Networks
•Enhanced overall architectures to support needed enablers •End-to-end Horizontal and Vertical Network Convergence •AI/ML for Digital Infrastructures •End-to-end Network Automation •Autonomous Systems and Networks •Advanced QKD Networking •Connectivity as a Shared Critical Utility •Wireless and Wired Tera-Broadband technology: •Wireless (electromagnetic and visual light waves): •Larger massive MIMO systems •No “Cell” Radio Networks with distributed smart mMIMO systems •TeraHertz Communications •Wired optical: •Photonics •Optical smart networks •Optical spectrum: Sliceable Optics, shared lambdas •Increasing Bandwidth in Optical Network: use of additional bands, Higher modulation schemas •Quantum communications •QKD •Entanglement	•Industrial features of 5G and beyond •Time Sensitive Networks •Precision Positioning •Private Networks •More Indoor techs like Terahertz, Visible Light Coms, •Non-3GPP convergence (like Wi-Fi, Industry Net Standards…) Tera scale Internet of Things (IoT)	•Macro/Micro Grids’ concepts related technologies adapted to ICT as it exists for Energy •Full end-to-end Slicing of physical networks and infrastructures (see Smarter Networks) •Cyber-security •Quantum QKD •AI/ML & Big Data Real Time Analytics based Security •Reinforcement of Sovereignty •Cyber-attack based Disaster recovery •Trust enablers •Security •Auditability •Transparency	•SAT enabled 5G/B5G/6G •Moving ICT to SAT •RAN in SAT (Space-RAN?) •CORE in SAT (Space-CORE?) •MEC in SAT (Space-Edge Dc?) •MBH in SAT (Space-Mobile Backhaul?) •Value Added Services in SAT •Earth Meshed Network (including Oceans) •SAT to Ground •SAT to Sea •SAT to Air Objects & IOTs •SAT to SAT •=> SAT to All •Multimodal SATs •Combining GPS info with Network info •Combining Observation modalities with Network info •Avionics communications •Air to Ground •Air to Air •Drones / HAPS •Balloons?	•Deeper “edge-ification” for Distributed, collaborative and hierarchical AI/ML •More Multi-Purpose Adaptable Networks: •Universal adaptive core •Programmable network Operating System •Advanced very large-scale monitoring (for AI, ML, Dl…) •Distributed AI/ML •Consuming •Producing •Supporting •Intelligent and Automated Dynamic Spectrum Management : •Electro-magnetic Spectrum: Horizontal & Vertical Flexible Sharing CBRS, DSS, LSA, LAA, MultiFire, new enablers… •Optical spectrum: Sliceable Optics, shared lambdas •Full Slicing •Real End-to-End leading to: •Multi-layered multi-tenancy •Full neutral hosting •Multi-Dimensions sliceable (incl. Spectrum and Time) •Thanks to: Deeper Network Programmability

Figure 6 : Candidate enabling technologies to be addressed.

3. CELTIC-NEXT Calls planning

3.1. CELTIC-NEXT project call planning.

3.1.1. Number of calls per year

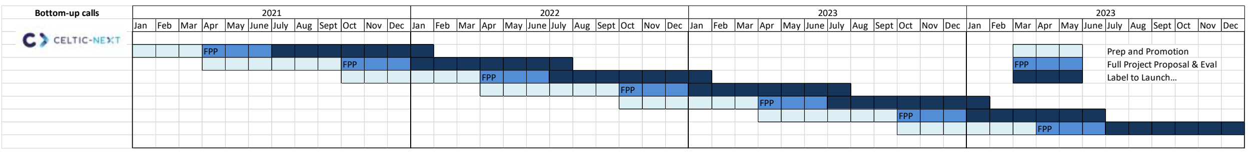
The experience within the CELTIC-NEXT community is that the community appreciates two opportunities in the calendar year to present their project ideas for consideration.

Accordingly CELTIC-NEXT plans to issue 2 single stage cluster-level "bottom-up" calls per year, one in Spring, one in Autumn for each AOP period.

In addition to bottom-up calls, CELTIC has been regularly successfully launching so-called “Flagship” projects / calls.

3.1.2. Provisional Calendar

The spring call 2021 is now closed (Submission date was 12/4/2021). Autumn call submission deadline is now fixed to 22/11/2021.



3.2. Flagship projects

CELTIC Flagship projects are special projects, finding birth when both Industry and Public Authorities show a common joint strong interest into developing a specific topic, like CELTIC had with SASER, SENDATE and more recently with AI-NET. Those projects are usually of the range of several tens of million Euros for a 3-5 years duration.

They are very successful. They are a balance of bottom-up and top-down approaches. One could say that they are at the crossroads of those two models. They are the result of a great collaboration and discussion between all parties involved.

3.2.1. Number per year

The previous objective was to launch a flagship during the last year of the precedent one. CELTIC-NEXT is analysing if it would be possible to increase the rate to one every 2 years.

3.2.2. Provisional Calendar

CELTIC-NEXT is currently starting the AI-NET Flagship project and sub-projects. There is still a good opportunity for a new flagship to happen in 2022.

3.3. Topics of interest for future calls

For its own ICT Cluster community, CELTIC-NEXT will run bottom-up calls that will welcome projects corresponding to the various topics as exposed in the strategic roadmap (section 2).

The World goes digital. Most of the existing and upcoming verticals will contain digital elements, interconnected together as systems of systems, thanks to networks of networks, to produce goods and deliver services to humanity and to some extent to the Earth itself, while guaranteeing a sustainable future for both.

Future applications are going to be complex systems integrated with many sub- or peer systems in the same or other application domains with huge requirements for communications and interconnections. Their interconnection via networks of both public and private networks, with an intimate interlacing of both to ensure quality and performance, is at the core of the ICT community and the ambitions of CELTIC-NEXT.

Therefore, CELTIC-NEXT will support many projects where ICT technologies are enablers of other verticals. They should also support human aspects and societal goals as described in the UN Sustainable Development Goals (SDGs)[3] and the UN Digital Cooperation Strategy Roadmap[4]. Unlike the nascent EC SNS[5] undertaking, which restricts its work to a pre-defined selection of the UN SDGs, CELTIC-NEXT will stimulate collaboration on all UN SDGs, as per EUREKA Public Authorities expressed priorities.

Examples include:

Human Centred Technologies and Services, for an Augmented Life Experience

- Digital divide elimination
- Smart Regions/Cities/Buildings/Homes
- Smart Transportation
- Smart Tourism
- Sustainability & Efficiency of Smart Energy Grids
- Public Safety & Crowd Control
- E-Health & Care
- Users in Control and Trust of offered services
- Digital support for Education and Remote Education
- Digital (Media, Gaming, Sports, Culture and Entertainment)
- Remote working and Nomadic Working (Digital Nomads)

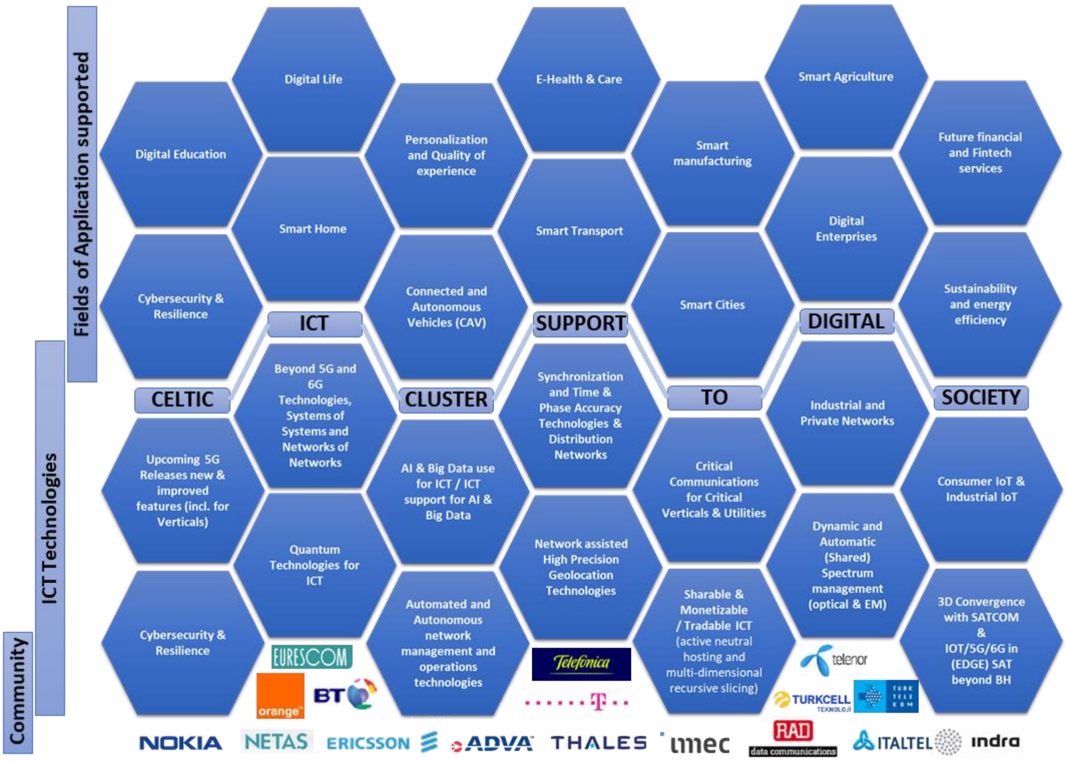
Full industrial digitization and support of vertical industries

- Digital Enterprises
- Private Networks for Smart Manufacturing (Indus. 4.0)
- Smart Logistics (geolocation IOT networks)
- Smart Agriculture
- Future Financial and Fin-Tech
- ICT support to third party AI based applications
- Connectivity Grid / Telecom Infra as 4th Utility, like Energy

Futuristic use cases

- Holographic "Teleportation"
- "World" Real-time Synchronous Digital Twin

In line with its charter, CELTIC-NEXT will fully support the Identified services domains and ICT technologies from the CELTIC-NEXT roadmap:



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[3]https://www.undp.org/content/undp/en/home/sustainable-development-goals.html ; https://unstats.un.org/sdgs/report/2020/

[4] https://www.un.org/en/content/digital-cooperation-roadmap/

[5] https://5g-ia.eu/sns-horizon-europe/