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What is 5G (Really) About?

White Paper

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List of Acronyms

2G	2^{nd} Generation
3D	3 Dimension
3G	3^{rd} Generation
4G	4^{Th} Generation
5G	5^{th} Generation
D2D	Device to Device
E2E	End to End
EU	European Union
ICT	Information and Communication Technologies
IoT	Internet of Things
ISP	Internet Service Provider
KPI	Key Performance Indicator
LTE	Long Term Evolution
M2M	Machine to Machine
ms	Millisecond
NFV	Network Function Virtualisation
OTT	Over The Top
PPP	Public Private Partnership
QoS	Quality Of Service
SDN	Software Defined Network
WiFi	Wireless Fidelity
w.r.t	with respect to

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Executive Summary

The Advanced 5G Infrastructure, defined as the ubiquitous ultra-broadband network that will carry the Future Internet, is not only an ***evolution*** of current generations, but, more significantly, a ***revolution*** in the ICT field that will enable efficiently new ultra reliable, dependable, secure, privacy preserving and delay critical services to everyone and everything, such as cognitive objects and cyber physical systems. "Full Immersive Experience", enriched by "Context Information", and "All as a Service", will be the main drivers for a massive adoption of the new technology components and market uptake, beyond the current "Client-Server" model, in which the network infrastructure reduces to an intelligent pipe of bits. This calls for a complete redesign of the architecture, services and service capabilities of the new infrastructures, and a re-thinking of interfaces, access and non-access protocols and related procedures, functions, and advanced algorithms, for authorization, authentication, establishment, maintenance and reconfiguration of ICT services and any type resource among cyber-physical entities, especially at the edge, for example, around the end users (prosumers). Several challenges still need to be addressed to meet and exceed the expected key performance indicators, in terms of throughput (1000x more in aggregate and 10x more at link level), service-level latency (1ms for tactile Internet and below 5ms for 2-8**K** change in view, at 30-50Mb/s), coverage (seamless experience), battery lifetime (10x longer), QoS, manageability, etc. Moreover, the advanced 5G infrastructure needs to be largely ***flexible*** thus meeting foreseen and unknown requirements, in alignment with current and future stakeholders' expectations (needs). A large adoption of cloud computing, software networks and network functions and services virtualization will make the 5G possible. Most of the research and innovation efforts need to be in place well before 2016; intensive standardization activities and large field test trials and testing will take place globally before 2020; beyond that, commercial products will be most probably available in the market. The approximate roadmap applies to infrastructures and devices for human and machine type of traffic. Europe can make this vision happen through crucial investments in 5G technologies and related measures to focus and strengthen its knowledge in the new ICT fields. Ultimately, we believe the EU 5G Public Private Partnership (5G PPP) to be a viable initiative for the EU ICT industry achieve a competitive advantage in the global marketplace by contributing to the research and investigations of the new technologies that will characterize the next generation of ICT infrastructures.

1 Rationale

Today, for the first time, especially thanks to the deployment of LTE (4G), we are witnessing the convergence of "Cloud Computing", "Computing Power" and "Connectivity at High Speed", all realized over the bitpipe model of the current Internet [1]. It is now time to go beyond this model and design 5G, i.e. the next generation of ubiquitous ultra-high broadband infrastructure that will support the future Internet, and provide delay-critical and ultra reliable, secure and dependable services to billions of smart objects and cyber physical systems, such as cars, robots and drones. With 5G, the Information and Communication Technologies will generate new services at low cost not only focusing on providing a seamless and efficient communication capability as in the past, but also trying to really improve the way we interact among ourselves, with the final target of improving our lives. Communication services will be free in most of the cases, and will monetize all those applications, machines and things, that will be offered as a service, thus allowing the shift, and that really matters, towards a more and more real Information-oriented Society.

One of the key drivers for the development of a future 5G infrastructure will be the growing **ecosystem of things** around the end user, or prosumer, as new terminals will retrieve and generate information through ephemeral networks of cognitive objects and cyber physical systems in their proximity, independently from the network infrastructure availability. It is the latter distributed intelligence in future smart phones, drones, robots, and any smart objects – with or without network assistance – that will provide the ultra reliable, secure and privacy preserving, dependable, and performing connectivity services with extreme low latency, when necessary. The distributed intelligence in pervasive local actuators will be one of the fundamental catalysts in the interest of today's operators, at the expenses of the OTT players, which will keep monetizing through innovation at the application layer [2].

5G will be the integration of new mobile and wireless access systems (very broadband systems and IoT) with legacy networks in order to use deployed investment like LTE, 3G, 2G, WiFi, satellite etc. as long as such systems will be still in operation. All these systems should cooperate and interwork seamlessly. 5G services will place very stringent requirements in terms of achievable coverage, data rates, latency, reliability and energy consumption. In most of the cases, not all of these requirements need to be simultaneously met. However, the advanced 5G infrastructures need to be flexible and adaptable to diverse use cases and scenarios.

For instance, for seamless integration of smart objects, 5G networks are expected to provide measurable and provable security, as well as a service-level delay below 5 ms when needed, with 99.999% transmission reliability and approximately 100% availability. For reproducing real 3D scenarios, like big events and professional transmissions, where an immersive "dreaming" experience is achieved through capturing and rendering signals coming from a large number of sensors and multi-directional transmitters, any future 5G infrastructure is expected to cope with 30-50 Mb/s, for a single video transmission, and perform most of the light field and sound field processing in the network, as terminals are likely to receive only a portion of the full set of views/channels available. This will require the network to adapt the data stream with (close to) "zero latency", according to decoder characteristics. In order to support applications like the "tactile Internet" the service-level latency should be reduced to about 1 ms. The 3D full collaborative and immersive experience are expected at home, in cinemas, theatres, public arenas, vehicles, vessels, aircrafts and especially using the next generation of devices without the needs of wearing glasses or binaural receivers [3].

None of the above stringent requirements can be met by any of the wireless technologies within the scope of the current standardization and network evolution frameworks. Satellite offers the wide broadcast coverage and high bandwidth but is challenged by latency, expense and saturation in areas with high user density, whereas terrestrial mobile achieves the connectivity to indoor and ground-mobile users but is economically challenged when user density is sparse or intermittent. It is thus necessary to research and develop new architecture concepts and technologies for accessing and delivering ultra reliable, fast, ubiquitous, dependable and secure wireless services, as well as rethinking network services and their capabilities, in terms of identity, mobility, trace preventing and connection management, while taking advantage of the faster-than-Moore's law affordability growth of storage for end user media cacheing with suitable content management.

This calls for a pan-EU 5G infrastructure, aiming at catalyzing innovation across the network, where the member states may play an important role in defining their relevant scenarios looking at an EU information-oriented society, where anyone will have the possibility of communicating and contributing to the good of our networked society, in terms of:

(1) High speed ubiquitous mobile access to global Internet and high bandwidth services, including the creation of an environment where miniaturized smart systems (with in-built "intelligence") are able to provide more intelligent services anytime anywhere

(2) High level of democracy as a fast medium for the population of high diversity cultural groups to access to information related to candidates and parties standing for election at national and European level.

(3) Higher individual and societal wellbeing by allowing for mobile health and wellness services anytime anywhere

(4) Booming generation of jobs in a diverse pool of activities and business models as well as across many sectors, created by the information highway network.

(5) Generation of high level of cooperative and collaborative works by different businesses around Europe and intercontinental commercial entities.

(6) Creation of an environment in which risks of criminal actions and attacks are minimized, and effective solutions to disaster and recovery areas are easily and rapidly implemented.

(7) Automation of many tasks, during our daily activities, that could be offloaded to machine, robots and drones, following the "Smart Factories", "Smart Energy" and "Smart City" paradigms.

In other words, we see the role of 5G as that of providing a universal communication environment that enables to address the wider societal challenges such as in transport, automotive, societal safety, employment, health, environment, energy, manufacturing and food production. This will be achieved through flexibly aligning stakeholder incentives by virtue of being truly programmable, secure, dependable, privacy preserving, ubiquitous, and flexible, while minimizing the costs per bit by efficiently harnessing all available communication capabilities and reducing the system power consumption, e.g. by harvesting accessible energy from the environment and other means.

This wider diffusion of wireless communication and its enabling networks will allow for addressing the societal challenges at an unforeseen economy of scale, moving away from vertical silos and truly enabling cross-value chain collaborations across the many sectors that utilize the common 5G technologies. Hence, 5G will enable the development of an ecosystem that have been so far dispersed across vertical solutions with high barriers of entry for new market players, including ISPs and application developers, as well as prohibitive costs and energy per bits in the existing solutions. The effect of a common information and communication substrate will be the introduction of a much wider range of stakeholders into the 5G ecosystem, compared to any existing single ICT-based solution, ranging from individual people and digital asset owners over vertical sectors such as transport, energy, health, manufacturing, food production, broadcast to public bodies like municipalities and public safety organisations. Such widening of the stakeholder community will require an openly accessible communication environment in which solution providers as well as network owners can strive towards addressing the specific societal challenges that are addressed in every solution in conjunction with the policy challenges in security, privacy and energy footprint that will lie ahead. Furthermore, with many more people expecting to have the same coverage when travelling (on cruise liners, passenger aircraft, high-speed trains and in holiday villas), it is key to allow for seamless extension of 5G services anywhere anytime, e.g., through satellite technology.

This vision of a deeply penetrating common information and communication substrate will require a re-thinking of how we design the overall ICT system, allowing reconfiguration of value chains (and therefore the underlying provisioning of the communication substrate) in real-time, while providing an evolutionary path for integrating the advances in radio and network technologies. Such endeavour has to address the well-known set of specific technological challenges, e.g., providing 1000x more bandwidth to end users while reducing the end-to-end latency to about 1ms when needed, as already mentioned above. This re-thinking requires an orchestrated effort of collaboration across Europe that takes the individual technological advances and embeds them into a system that we can truly call 5G.

Europe can make this vision happen through crucial investments in 5G technologies and related measures as well as actions to strengthen the know-how and ensure the EU leadership in the field of ubiquitous ultrafast broadband, ultimately re-enforcing European data protection and supporting the most plausible scenarios and valuable use cases for all (not only urban areas) expected in 2020 and beyond.

The 5G Public Private Partnership (5G PPP) is the manifestation of the orchestrated effort for the EU ICT industry achieve a competitive advantage in the global marketplace by contributing to the research and investigations of the new technologies that will characterize the next generation of ICT infrastructures.

2 Research priorities

The following vision of what 5G stands for reveals a plethora of challenges that we can outline:
5G strives to provide a universal ICT infrastructure that addresses wider societal challenges through a flexible alignment of stakeholder incentives by virtue of being truly programmable, secure, dependable, privacy preserving, and flexible, while minimizing the costs per bit by efficiently harnessing all communication capabilities and reducing the system power consumption by harvesting any kind of accessible energy from the environment.

First, this vision points towards a significantly increased (in comparison to earlier generations) set of stakeholders that 5G needs to accommodate when providing communication solutions. Examples of stakeholders are:

- Individual and communities of people.
- SMEs, corporations, not-for-profit and social organizations.
- Digital asset owners, such as public transport and utilities authorities and organisations.
- Vertical sectors like energy, health, manufacturing, robotics, environment, broadcast, content and creative industries, transport, smart cities.
- Municipalities and public administrations.
- Public safety organisations and defence bodies.

Providing communication solutions for this large set of stakeholders with current communication solutions is intrinsically difficult due to the large set of requirements that needs addressing at any point in time of deployment. These requirements lead to a number of **key challenges** that 5G technologies will need to address for meeting the expected key performance indicators (KPIs):

- **Throughput**: provide 1000x more available throughput in aggregate, as well as 10x more speed to individual end users, in order to enable fully immersive experiences. This may require to integrate new forms of broadcast services.
- **Latency**: provide service-level latency down to about 1ms (when needed) for tactile Internet, interactive and immersive experiences as well as standard Internet services.
- **Coverage**: with many more people expecting to have the same coverage when travelling (on cruise liners, passenger aircraft, high-speed trains and in holiday villas), it is key to provide seamless extension of 5G services anywhere anytime. IoT coverage to wide areas involving sensors and M2M connections are ideal services to make use of satellite wide area coverage.
- **Battery lifetime**: provide 10x better battery lifetime for low throughput solutions such as sensors.
- **Harnessing challenge**: exploit any communication capability, including device-to-device (D2D), for providing the most appropriate communication means at the appropriate time.
- **Quality of Service**: in order to allow for optimizing the **Quality of Experience**[1] **(QoE)** for the end user, 5G should provide differentiated services across various dimensions such as throughput, latency, resilience and costs per bit as much as possible independent of users' location w.r.t. the antennas deployment geography.
- **Service creation time**: enable the creation of user experiences from the application over the individual service components down to the individually participating network(s) in a matter of seconds or less.

[1] **QoE** is the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and / or enjoyment of the application or service in the light of the user's personality and current state.

- **Privacy by design**: provide accountability of users within the communication substrate and enable truly private communication when needed, aligned with policy constraints.
- **Open environment challenge**: enable horizontal business models by opening the right business interfaces within the system in order to enable flexible operator models in a multi-tenancy fashion.
- **Location and context information**: provide positioning and context capabilities in the sub-metre range in order to enable the Internet of everything, e.g., through the integration of cellular and satellite positioning systems**.**
- **Manageability**: Improve manageability of networks in order to reduce the need for manual management and reduce the human involvement.
- **Harvesting challenge**: devise a radically new approach to provide devices with power, which not only has to come from batteries, but is also obtained by harvesting existing environmental energy.
- **Hardening challenge**: deploy a communication system through a combination of bearer techniques such as cellular and satellite that is intrinsically robust to attacks from malicious entities as well as to natural disasters; a resilience without which the smart-grid/smart-city paradigm will never be achieved.
- **Resource management**: provide access agnostic control, policy and charging mechanisms and protocols for dynamic establishment, configuration, reconfiguration and release of any type of resource (Bandwidth, Computation, Memory, Storage), for any type of devices (e.g. terminal, car, robot, drone, etc.) and services (e.g. Network, Security, Data, Knowledge, Machine, and Thing as a Service), including in E2E fashion when necessary.
- **Flexibility**: devise truly flexible control mechanisms and protocols for relocating functions, protocol entities and corresponding states in a truly end-to-end manner, leveraging programmable network technologies such as SDN and NFV.
- **Authentication**: provide identity management solutions for any type of device (terminal, car, robot, drone, etc.) with access agnostic authentication mechanisms that are available on any type of device, device to device and network to device.
- **Charging**: provide methods for flexible pricing mechanisms across and between different parts of the future 5G value chain in order to enable pricing regimes that are common across the industries that will utilise the future 5G infrastructure.
- **Energy efficiency**: Wireless/mobile broadband infrastructures account for more than 50% of the energy consumption of telecommunication operator networks, while the amount of global energy consumption of ICT approaches 4.5% with a rising trend [4]. It is important that future 5G networks meet requirements and challenges in an energy efficient manner (by achieving 90% of energy efficiency compared to 2010 levels).

The individual whitepapers on radio and network technologies outline the particular research priorities that can be derived from addressing these challenges. These priorities include, but are not limited to, research into new radio waveforms, new joint access/backhaul designs, new routing solutions for backhaul and core networks, new caching solutions for reducing service-level latency, new low throughput solutions for sensor deployments and many more.

From a system level perspective, our vision outlines one particular challenge that overarches all technology-focussed research priorities; this challenge is that of **flexibility**. Given the wide range of stakeholder incentives and requirements, future 5G system must provide an enormous degree of flexibility. This challenge drives 5G away from the rather rigid pre-5G designs with limited service classes available to its users and few assumed deployment models at the communication substrate level. Specialized network components provided as specialized hardware boxes, based on commonly agreed standards, reflect this rigidity in design. In order to achieve the necessary flexibility of 5G systems, we foresee a high degree of **programmability** of otherwise standard network-enabled hardware components, such as reflected in the current network function virtualization (NFV) efforts. This programmability pushes the resolution of incentive conflicts from the early standards phase to the later deployment phase where network emulation as well as validation of software components paves the way to significantly reducing the service deployment time from several days to minutes or even seconds. The programmability also provides the ability to account for the usage of resources across the network, enabling the envisioned flexible incentive alignment across several stakeholders. Furthermore, with resources interpreted as that of computing, storage, volatile memory and bandwidth, the envisioned programmability of the network will also facilitate solutions for the aforementioned guarantee challenge at the system level by allowing for optimizing across all these resource dimensions towards a single deployed solution. Combining flexibility and programmability in future 5G systems should also allow to build complex, mission-critical services with specific requirements in terms of service quality, where a dedicated physical infrastructure would be normally required. Furthermore, the future 5G system needs to perform in an **energy-efficient manner**, by meeting at the same time all the necessary 5G KPIs in line with the 5G vision. This trend will result in the design of energy-efficient hardware that ultimately reduces the energy consumed per bit.

The separate whitepaper on virtualization will elaborate on the specific research priorities that stem from this aspect of 5G. Beyond these identified technology challenges, we also identify research priorities needed in economic and policy research that investigate the impact of this new flexibility on business and standards processes as well as on policy-making processes. We believe that this research will be transformative to today's processes. For instance, we need to investigate the role of standards as a way to agree on technological and business interfaces within the system in the light of upcoming virtualization solutions. We will also need to investigate the impact of new spectrum management approaches on spectrum policy, possibly integrating the technological solution (e.g., the exchanged information for spectrum sensing) into the policy approach itself. Last but not least, the flexible alignment of incentives, as envisioned by our 5G vision, will truly enable fluid information-driven markets through our 5G platform. We will need to study the potentially transformative changes within the many industries that 5G intends to provide solutions for in the light of this new economic market fluidity. For instance, we can already see today that the 'app economy' of smartphone-based applications has had an impact on areas such as public transport as well as health. Quantifying this impact, identifying new business models as well as fostering emerging stakeholders in these future markets are the priorities of this economic research in the 5G context.

3 5G Evolution Roadmap

Timeline / Technology	< 2015 Features	<2020	2020+ Features
Cellular Broadband	• 5G Technical and spectrum requirements • 4G evolution	• Standardisation • Radio interface • Radio access and converged core architectures and technologies • SDN/NFV	• Deployment • New releases

		Technologies and SD Networking • D2D • Field trials and testing	
Narrowband terrestrial network (e.g. for M2M and IoT)	Mix of different proprietary and standard technologies such as 2G, 3G	• Standardised radiointerface • Migration to 4G • Field trials and testing	Integration of M2M and Cellular systems
Satellite	Mix of different proprietary and standard satellite technologies: FSS[2]/BSS[3] (IP based), MSS[4] (2G and 3G) Hybrid broadcast/broadband (FSS/BSS)	4G service delivery via FSS/BSS/MSS 5G Satellite Radio-interfaces standardised Field trials and testing	5G service delivery via FSS/BSS/MSS Integration of MSS satellite in the M2M/IoT sensor network for global coverage

4 Summary and Conclusions

The communication industry has undoubtedly changed the lives of many people and transformed the way we do business in many areas. It is our vision that 5G will push this transformation beyond the current status quo by providing a truly universal communication substrate for an unforeseen range of industries without the need for vertical silos of ICT solutions. For this, it is required that we not only develop key technologies that advance the state-of-the-art in terms of performance and also energy efficiency, but it is also required that we re-think how we design systems in the light of a wide set of requirements that goes way beyond current 4G systems. For this, we believe that *flexibility* and *programmability* are key principles in future 5G systems, enabling a flexible alignment of incentives at any point in time while minimizing the need for standardization processes at many levels of the system. With this, we foresee service deployment times being reduced from days to mere minutes or even seconds while enabling a wider range of deployment-specific requirements being met, possibly with hard guarantees.

This vision of 5G requires a broad research agenda as well as an orchestrated effort where this agenda is maintained and refined in collaboration with key stakeholders and funding agencies. This whitepaper provides a first insight into the priorities stemming from this 5G vision and therefore a formulation for the raison d'être of the 5GPPP association.

[2] FSS = Fixed Satellite Service
[3] BSS = Broadcast Satellite service
[4] MSS = Mobile Satellite Service

5 Recommendations

R1) Investigate and define disruptive network architectures harnessing all available network technologies and services to address the 5G challenges.

R2) Investigate, develop and deploy the necessary access, networking (core & transmission) and virtualization technologies that will drive the advances of 5G system components and meet the KPIs outlined in Section 2.

R3) Investigate, formulate and incorporate the driving system-level principles, such as flexibility and programmability, that will allow for implementing the 5G vision across the developed technologies.

R4) Investigate, formulate, and foster the right business models for 5G systems that allow for a virtuous cycle of investment across the entire existing value chain as well as possible new ones.

R5) Engage with the wider stakeholder community through efforts like roadshows, common test beds, development and early deployment efforts, and others.

R6) Investigate the right policy and standardization framework for managing networked assets, spectrum as well as computing resources to foster the truly cross-value-chain collaboration in 5G.

6 References

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