Horizon 2020 Advanced 5G Network Infrastructure for Future Internet PPP

Industry Proposal (Draft Version 2.1)

Creating a Smart Network that is Flexible, Robust and Cost Effective

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In Brief

The use of telecommunication services in Europe has grown remarkably in the last two decades. Responding to ever increasing demand for data usage it is today commonly agreed that a continuous long-term investment into research and development and the deployment of communication systems standards has to be ensured. Global standards are a fundamental cornerstone in reaching ubiquitous connectivity, ensuring worldwide interoperability, enabling multi-vendor capability and economies of scale. Early investments of technology research are necessary to develop and build these global standards – today providing a complete and ready platform for a wide range of businesses of the entire value chain in Europe and beyond, enabling employment and economic growth. Discussions are currently ongoing between stakeholders to target a new partnership initiative (e.g. by means of a Public-Private-Partnership – PPP) under the European Horizon 2020 (H2020) framework to address Information and Communication Technology (ICT) Infrastructures and Communication Networks – A timely initiative to further strengthen European industry's competitiveness in this area.

1. Vision

This section describes the problem definition, the background of the proposal, the stakeholders behind this proposal, the added value of action at EC level and via a contractual PPP, the overall long term vision and finally the strategic and specific objectives of the PPP in the context of EC Horizon 2020 (H2020) programme and related policy areas.

1.1 Scene Setter

This sub-section addresses the problem definition, the importance of the sector to the EU in terms of socio-economic and environmental indicators and perspectives for further development, and the background of the proposed initiative (e.g. EU policy, ETP, etc.).

1.2 Actors behind this Proposal

1.3 Added Value of Action at Union Level

This sub-section explains why Europe needs to act jointly and now.

1.4 Added Value of Implementation via a Contractual PPP

This sub-section details the added value of implementation via a contractual PPP as compared to the collaborative research, or by industry sector alone.

1.5 Overall Long Term Vision of the PPP

According to ITU statistics the number of subscribers is growing globally. The number of fixed telephone lines with low global penetration is decreasing, whereas the number of mobile subscribers is growing fast globally. With respect to the increase of Internet users also the number of fixed and mobile broadband subscriptions is increasing. Broadband access is growing fast in particular in developed countries. However, globally and also in developing countries the number of subscriptions is increasing. Further growth of the European ICT market can be expected by an upgrade of European communication networks to real broadband systems with significantly higher sustainable throughput rates than today and an increased use of communication networks for other critical infrastructures.

In addition, the global Internet with more than 2.4 billion users globally (status June 2012) is growing further. This development is requesting reliable and highly available communication networks, which provide the necessary QoS and security in order to support all kinds of Internet based services and applications. European industry is supporting this growth by developing and deploying, e.g. the necessary networks. It is expected that data traffic for different traffic types will further grow significantly. A CISCO study is estimating an exponential growth in the coming years. An Ericsson study is comparing traffic from voice communication, data traffic from mobile phones and mobile PCs/tablet. Voice traffic will nearly remain constant and very small compared to data traffic in future and we expect a 40-fold increase between 2010 and 2015 for the latter. Machine-to-Machine communications (M2M) for example in the Internet of Things (IoT) and sensor-based networks is an additional driver for traffic growth.

Drivers of the Future Internet are all kind of services and applications from low (sensor and IoT data) to high throughput rates (e.g. high quality video streaming) and low to high allowed latency and the variety of devices, which support such services and applications. Communication networks as the interface between user devices and the services and applications domain have to provide the necessary performance and system capacity in order to cope with the expected traffic growth. With respect to the different innovation cycles in the services and applications domain of several months or around a year compared to radio interfaces in the order of several years the communication networks cannot be designed based on well established requirements. It is necessary to make challenging working assumptions on major basic technical requirements based on best today's knowledge in order to meet the needs in the 2020 time frame. To a certain extend software based systems will provide the flexibility to adapt to new requirements

and to easier introduce innovation into deployed systems. Flexibility in technical requirements and the system design are key to enable further innovation and to meet today unforeseen service requirements. Therefore, from the long-term vision perspective future systems have to offer high flexibility in data throughput, have to allow for very low latency and adaptability to new schemes. In particular video applications are increasing requirements for more available bandwidth or data throughput. On the other hand sensor data and IoT systems may require the efficient support of very low data streams and bursty traffic.

In the coming years, the ever-increasing demand from customers and M2M systems will impact the network, and new technologies will be introduced for transmission, (broadband) connectivity, switching, routing, naming/addressing, storage and execution.

Our vision is that ten years from now, telecom and IT will be integrated towards a common infrastructure massively based on general purpose and programmable hardware that will offer resources for transport, routing, storage and execution. Network equipment will become "computing equivalent" equipment that gathers programmable resources based on virtualisation technologies.

The acceleration of innovations in technologies and in services combined with a competitive market that is evolving very fast (Facebook did not exist few years ago) make the prospective exercise in network evolutions very difficult. However, some key points can be highlighted:
- The different bricks of future networks have already been identified: They will rely on high performance fixed and radio access systems, high-capacity optical access, backbone & data centre networks, mobility support, cloud computing compatibility, virtualisation, software defined network, and information centric network technologies.
- Future networks will not only be based on transport and routing/switching technologies anymore: They will also embed computing and storage resources in a converged infrastructure to orchestrate the delivery of IT and network services.
- Future networks will cooperate with home networks and devices and will be able to adapt their behaviour depending on user's or terminal's contexts. They will be able to manage access selection in order to provide dynamically the best available network.
- Security will be a key requirement of future networks.
- They will be more flexible, and will be able to evolve more easily than today: The infrastructure will be more open. At the same time, embedded security will be embraced as general concept.
- Future networks will have to provide a significantly higher system capacity than today.
- Future networks should be based on common network management for mobile and wireless as well as the fixed network for economic network deployment and operation.

The communications industry identified the following topics for the development of future networks, which are the basis of the Infrastructures PPP:
- Faster, more powerful and more energy efficient solutions for high capacity access, core and data centre networks for a wider range of services:
  o Wireless Networks.
  o Optical Networks.
  o Automated network organisation.
  o Implementing convergence beyond the access last mile.
- Re– designing the network for more flexibility and software-programmability:
  o Information Centric Networks.
  o Network function virtualisation.
  o Software Defined Networks.
  o Networks of Clouds.
- Ensuring Availability, Robustness and Security.
- Ensuring capable end user devices and high amount of other connected devices.

These topics will be further detailed in the sub-section 2.1 of this document.

1.6 Strategic and Specific Objectives of the PPP

This sub-section details the strategic and specific objectives of the PPP in the context of H2020 programme and related policy areas.

The Infrastructures PPP will mainly address the Industrial Leadership Priority in Horizon 2020 and in particular the challenge Information and Communication Technologies (ICT) and the action line Future Internet.

The strategic objectives of the Infrastructures PPP will be:
- Societal objectives
  - Contribute to EU 2020 objectives to provide ubiquitous broadband access of interoperable and globally standardised communication networks in order to overcome the digital divide in Europe between densely populated areas as well as rural areas to develop economy across all regions in the European Union.
  - Accelerate the adoption and use of advanced ICT services in Europe.
  - Attain European leadership in uptake and use of ICT technologies.
  - Advance the critical communications infrastructure in Europe and its implementation.
  - Support the massive amount of new applications that networks will have to support, from IoT to UHDTV.
  - Improve the energy efficiency.
- Economic objectives
  - Maintain and improve the European strong position in research, development and standardisation of future communication networks in cooperation with other regions in order to provide globally accepted standards, which ensure interoperability and economy of scale.
  - Reinforce the European industrial leadership in Network and Information Systems.
  - Strengthen industry competitiveness and favour innovation through openness by respecting legitimate interests of partners on securing IPRs and know-how with respect to global competition.
  - Accompany the forthcoming convergence between Telecom and IT sectors.
  - Drive the integration of the services and the intelligent infrastructures for highly optimised service provision across heterogeneous networks.
  - Build up the know-how and IPR base in Europe for future systems in the research community and industry.
- Operational objectives
  - Create an appropriate environment for successful R&D activities.
  - Provide a governance model, which on one hand supports the goals of openness, transparency and representativeness and on the other hand ensures an efficient management with minimised overhead in order to use the resources as much as possible for actual research work.
  - Support an efficient information flow between projects by respecting the legitimate interests or partners with respect to confidentiality and access rights.

The Infrastructures PPP ambition is "**Creating a smart network that is flexible, robust and cost effective**".

The Infrastructures PPP will deliver solutions, architecture, standards and equipment for communication infrastructures:
- **Providing 1000 times higher capacity and more varied rich services compared to 2010.**
- **Saving 90% energy as today per service provided.**
- **From 90 hours to 90 minutes service creation.**
- **Secure, Reliable and dependable: perceived zero downtime for services:**
- **User controlled privacy.**

2. Research and Innovation Strategy

This section describes first the scope of R&D and innovation challenges to be addressed and the roadmap of identified research and innovation priorities and activities, including expected key outputs, secondly the key stakeholders along the value chain and finally the indicative timeline and estimated budget for implementation of the roadmap.

2.1 Scope of R&D and Innovation Challenges

This sub-section details the key technical and technological components of the Infrastructures PPP and the related research investigations to be addressed.

In order to cover the interests of the sector as best as possible this section is mainly based on the Strategic Research Agenda of the Net!Works European Technology Platform. Some elements have also been incorporated from documents of the NESSI ETP. In addition, information from the ETNO position paper "The Evolution of Network Infrastructure towards 2020" as well as the Net!Works Expert Group 5G position paper was used, which is supported by the NetSoc Coordination Action.

2.1.1 Faster, More Powerful and More Energy Efficient Solutions for High Capacity Access and Core Networks for a Wider Range of Services

2.1.1.1 Wireless Networks

Problem Description

Globally, the demand for broadband wireless communications is drastically increasing every year. A major factor contributing to this development is the ever-increasing number of users subscribing to broadband internet services using their mobile devices, which is accelerated by the trend towards flat-rate subscriptions. In addition to human users, different objects and machines are also increasingly getting connected. The amount of non-human users might be 10 times higher than the amount of human users after 10 years from now. Taking into account also all kinds of possible sensors embedded in objects and the surrounding infrastructure, like buildings and roads or even the surrounding nature, the amount of connected things might even grow to trillions. On shorter time frame new devices, such as smart-phones and tablets with powerful multimedia capabilities, are entering the market and creating new demands on broadband wireless access. Finally, new data services and applications are emerging, which are key success factors for the mobile broadband experience. All these factors together result in an exponential increase in mobile data traffic in the wireless access system, and such a trend is expected to continue to a similar extent over the next decade.

Recent studies and extrapolations from past developments predict a total traffic increase by a factor of 500 to 1 000 within the next decade. These figures assume approximately a 10 times increase in broadband mobile subscribers, and 50-100 times higher traffic per user. Besides the overall traffic, the achievable throughput per user has to be increased significantly. A rough estimation predicts a minimum 10 times increase in average, as well as in peak, data rate. Moreover, essential design criteria, which have to be fulfilled more efficiently than in today's systems, are fairness between users over the whole coverage area, latency to reduce response

time and better support for a multitude of Quality of Service (QoS) requirements originating from different services.

An emerging factor in the overall design of next generation systems is the energy efficiency of the network components and its deployment. The environmental impact by reducing the CO_2 emissions is essential for the ecosystem. Moreover, increased energy efficiency of the network reduces operational expenses, which is reflected in the cost per bit. This metric is important, given the expected traffic and throughput growth until 2020.

Focus Area Trillion of Devices

The objectives for solving the problem
The amount of non-human users might be more than 10 times higher than the amount of human users after 10 years from now. Taking into account also all kinds of possible sensors embedded in objects and the surrounding infrastructure, like buildings and roads or even the surrounding nature, the amount of connected things might even grow to trillions.

As part of the future network, end user devices need to be able to interact with other surrounding objects and sensors. This needs novel solutions and enablers, not to forget efficient use of earlier concepts for wireless proximity.

The conventional cellular structure will be complemented by novel network topologies in the IMT-Advanced compliant networks. Possible extensions include self-organising mesh-type networks, with direct user-to-user communication, and different levels of cooperation or coordination between end-user devices and/or network nodes.

The associated research
In this area the following research priorities are proposed:
- Significant improvements of the wireless network have to be explored, by strengthening the research efforts towards innovative cooperation and coordination schemes for network nodes, in a flexible heterogeneous network deployment, including wireless network coding systems applied to dense, cloud-like, massively-interacting networks of nodes.
- Enablers to find and interact with sensors and other devices in an efficient way, with respect to e.g. cost and energy.
- Novel network topologies.

Focus Area Single User Throughput

The objectives for solving the problem
New devices, such as smart-phones and tablets with powerful multimedia capabilities, are entering the market and creating new demands on broadband wireless access. New data services and applications are emerging, which are key success factors for the mobile broadband experience.

The associated research
In this area the following research priorities are proposed:
- How to support 10 to 100 times more traffic per end user without increasing resource usage in terms of cost or energy.

Focus Area Scalability and Capacity

The objectives for solving the problem
Future networks will need to be deployed much more densely than today's networks and, due to both economic constraints and the availability of sites, will need to become significantly more heterogeneous and use multi Radio Access Technologies (RATs).

The operation of the network needs to be able to scale its operation depending on the widely varying traffic capacity needs and still remain energy efficient.

<u>The associated research</u>
In this area the following research priorities are proposed:
- How to make best use of novel possibilities offered by denser and more heterogeneous Radio Access Technologies (RATs).
- How to support widely varying traffic needs efficiently.
- New radio technologies (scale of channel modelling to small and complex scenarios, access, multiple antenna schemes, interference handling, etc.) must have a high priority, in order to meet the high requirements on 5G systems.
- Collaboration between wireless and optics experts, towards new network technologies exploiting wireless-optical convergence to deliver very high performance at reasonable costs.
- Derivation of a network control mechanism, comprising flow control, routing, scheduling and physical resources management that can provide QoS guarantees, and ensure network stability under a large set of service demands.

Focus Area Spectrum Availability

<u>The objectives for solving the problem</u>
Future wireless networks will face diverse challenges, amongst which are efficiencies in cost and resources, including the growing but still scarce spectrum resource. On a network topology level, the main tools to cope with the spectrum crunch are denser and denser node deployments and enhanced coordination. However, these require advancements in several other areas to make this feasible both technologically and economically, which are addressed in what follows.

Research on spectrum has focused or even hyped on the secondary use of the UHF band and TV white spaces, using mainly geo-location database techniques as the most basic way of spectrum sharing. The scope should be extended to opportunistic ways of spectrum sharing to any commercially viable segments of the whole spectrum, under the vision that any portion of spectrum that is not being used at a certain time and location can be used, regardless of the specific frequency range, bandwidth, and contiguity of available frequencies.

<u>The associated research</u>
In this area the following research priorities are proposed:
- Future network deployments have to allow for network/infrastructure/resource sharing on all levels, in order to meet the fast changing demands on network resources and operation.
- Cooperative spectrum-sharing techniques in non-homogeneous bands.
- Cognitive capabilities have to be incorporated into network design on all layers, supporting a flexible network adaptation at low operational costs, towards providing exactly the performance required for the determined user context.
- New radio access architectures, logical and physical separation between control and data planes, for achieving both spectrum and energy efficiencies.
- Full integration between mobile broadcasting and mobile broadband communications.
- Antenna systems fundamental limits, providing the performance benchmark for smart adaptability, including interactions with the user and the propagation channel, and taking an integrated approach where performance can be effectively optimised by appropriate sensing of the physical environment.

Focus Area End to End energy Efficiency

<u>The objectives for solving the problem</u>

Energy has been the target of significant research work in the past. Recently, FP7 EARTH project has found significant savings (more than 50%) for mobile broadband as provided by 4G. But it has also identified that its solutions by far do not provide the savings which could be theoretically achieved when employing traffic statistics. It identified that new concepts applied to future 5G networks and radio interfaces would help to come approximate optimal efficiency allowing for additional 80% savings. It should be noted that these savings are just what could be achieved when optimising a single network based on a single radio access technology.

For the wireless Internet of Things (IoT), new wireless network architectures, algorithms and protocols will be needed that are optimised for small and sporadic traffic. New applications such as M2M and IoT put an increasing burden on the networks from a signalling and control perspective. Signalling traffic for sensor networks can be a large drain of resources relative to the small amount of actual useful data being sent over the networks. We need to investigate new signalling mechanisms and architectures that scale to billions of devices. Efficient architectures for real-time and in-network processing of the data being generated need to be investigated to handle the amount of data being generated.

The associated research
- Air interface for improved energy efficiency allowing for additional 80% savings.
- Low power backhaul solutions (including optical) for an increasing number of small cells deployed to cope with the traffic growth.
- Power management techniques. Increasing peak data rates and shrinking cell size result in an increased randomness of the cell traffic and load. From a power consumption perspective, this means that the gap between dimensioning of the network resources and their actual usage opens. Energy efficient hardware and power management techniques to suspend functions and blank signals in a flexible way.
- Centralisation of the access network functions bears a good potential for cost and energy savings, since centralised multi-cell processing units can be under-dimensioned to exploit pooling gains.

Associated KPI (may be functional if cannot be quantified) to be defined.

2.1.1.2   Optical Networks

Problem description
Whether it is a voice call, an email, or a multimedia application, or whether we use a smart phone, computer or TV: optical networks always provide for a fast, secure and reliable transport of the required data, all the while remaining invisible to the user. Optical networks must undergo significant changes to cope with the increasing bandwidth demand and the requirements arising from new applications. With growing concern about energy efficiency and carbon emissions, significant changes are necessary in all network layers and segments (core/metro/access/data centre). Major needs exist to make optical networks faster, more secure, more flexible, more transparent, easier to use, and to bring them closer to the customer.

Networks tend to become more complex, while strong financial pressure requires optimising investments and controlling operational costs. This calls for new optical technologies able to support automation in the network deployments as well as elasticity and scalability in operation phases. Concepts need to address all layers, the physical layer as well as higher layers and also involves optimisation and planning across layers. Economically sustainable migration paths have to be found to allow new technologies to develop whilst exploiting existing infrastructures.

Broadband terrestrial backbones
The exponentially growing data consumption in fixed and mobile access puts more and more stress on the core of the network. In fact, based on various traffic measurements and predictions, traffic volume in the core network is expected to grow by roughly a factor of 10 within the next

5 years, and by a factor of 100 within the next 10 years. Peak throughput at core network nodes is expected to reach several 100 Tbps by 2020. Technologies utilised in optical networking are approaching fundamental limits set by physics and information theory, and will therefore require outstanding research effort to extend further.

Broadband fibre based access
Next-generation optical access networks are foreseen for providing multiple services simultaneously over common network architectures to different types of customers. Access networks capable of interconnecting higher numbers of users with a symmetrical bandwidth of up to 10 Gbps per customer are required. While the aim is to achieve the requested capacity, Quality of Service, and latency in the access network by exploiting the vast available fibre bandwidth, the challenge will be to keep the network cost affordable. A hierarchically-flat access network is targeted which provides convergence with next generation of mobile front-and back-haul technologies.

Broadband data centre connectivity:
New broadband applications are transforming the Internet into a content-centric cloud network, fuelling the proliferation of data centres and the related intra- and inter-data centre connectivity with Tpbs capacity. The new trend to warehouse-scale computing is raising the bar for high-speed data centre networks requiring unprecedented equipment densities whilst simultaneously imposing stringent requirements on the energy consumption. For emerging Exascale data centres, radically new architectural approaches are needed which make pervasive use of optical networking technologies to address next-generation throughput and latency requirements.

The objectives for solving the problem
Optical network infrastructures are a major asset for operators. These infrastructures based on packet and optical technologies needs to be more flexible, efficient, and easily manageable. These networks support legacy services but need to be optimised for delivering services with high growth potentiality such as media servers, high data rate services, e.g. upcoming new TV formats (3D, 4K)…

Therefore, the advent of high quality multimedia-rich terminals and services, expected to increase in the next years, lead operators to deploy high bit rate optical networks. FTTx roll-out is a global trend, mainly in Asia but also in Europe where main operators already deploy or have announced FFTx deployment for the coming years.

Beyond the need to develop next-generation technologies and architectures several other objectives have to be taken into account:

To make optical networks more transparent and secure. By removing unnecessary optical-electrical-optical conversions in aggregation nodes, routers and switches, whilst managing the resulting increase in heterogeneity in fibre types and network architectures. By allowing several bit-rates, modulation formats, and radio standards to travel across the same generic infrastructure, enabling future-proof and cost-effective convergence of mobile and fixed, metro and access networks. By providing optical layer security to enable secure exchange of data in the network on the lowest possible layer.

To make optical networks more dynamic and cognitive. By introducing true flexibility in photonic networks through fast-established circuits or packets, coping with varying traffic demands, benefiting from flexibility and elasticity in format, channel spacing or bit-rate. This while reducing latency, and managing quality of service at the photonic layer, so achieving autonomous operation of photonic network elements, including self-diagnosis, restoration and optimisation with efficient use of monitoring and adaptation capabilities.

To make optical networks faster. By deploying a disruptive mix of technologies to match the predicted capacity growth to a typical 10 Gbps per user in wired access and Tbps per channel in the core. This involves coherent detection with intelligent digital signal processing, exploiting all modulation spaces and multiplexing schemes, thereby increasing spectral efficiency, whilst expanding the bandwidth of optical amplifiers and improving their noise properties.

To make optical networks greener. By expanding the role of photonics from core down to home access, and promoting optical bypassing whenever possible. By turning photonic equipment to idle mode when possible, and performing power-efficient all-optical switching and processing as appropriate. By simplifying or removing unnecessary protocols, and performing energy-aware networking to reduce cost per transmitted and routed bit.

The associated research

The key research direction consists in designing solutions able to increase capacity, flexibility and scalability of optical networks, covering the following scope for optical access, backbone and data centre networks.

Optical Backbones

Future research on optical backbones should cover the design of transmission techniques with increased capacity (higher than 1Tbps per service/wavelength), as well as the introduction of more flexibility in the optical layer, the optimisation of multi-layer optical transport architectures and the design of innovative communication techniques based on full optical technologies

- Increased capacity transmission techniques: With bitrates of the order or even higher than 1Tbps per service/wavelength, distortions brought by the fibre would prevent reaching expected transmission performance if basic transmission techniques were to be used. Therefore, sophisticated but still cost-efficient techniques have to be investigated, including in particular forward error correction, all possible multiplexing technologies (e.g. frequency, time, polarisation and space) and different transmission bands or parallel systems. Also the use of new fibre types, switching elements, and amplification techniques must be considered.

- Flexibility in the optical layer: A better use of optical resources is required to increase the transport networks capacity. More flexibility in the optical layer helps to improve spectral efficiency, to reduce energy consumption and to optimise cost. Software-defined optical networks will allow a flexible end-to-end capacity assignment in which a multitude of parameters such as the optical spectrum allocation and an optical signal configuration (e.g. bit rate, forward error correction, symbol rate, modulation format, subcarrier count and spacing) can be adapted and dynamically changed. A control and management framework is requires which exposes the optical layer as a programmable network resource whilst hiding its complexity to the user.

- Multi-layer optical transport architectures: Innovative multi-layer optical transport architectures in relation with the capacity increase of the optical transmission system provide means to further improve the use of the available transmission resource and therefore offer a new dimension in the overall transport optimisation. New approach for information exchange between application, packet transport and optical transport layer are required. The programmatic control and virtualisation of optical network resources will increase network efficiency and allow operators to better monetise their network assets. New control paradigms, operational approaches, business models and service definitions are required for a wide-spread commercial adoption and need to be developed and tested under real-world conditions.

- Innovative communication techniques: Data routing in meshed optical networks can exploit new techniques (Sub-wavelength optical switching of the sub-bands which constitute super-channels as example) which should be optimised in terms of bandwidth resource usage and energy consumption.

Optical Access

A major research field relies on the design of new generations of optical access technologies, characterised by major evolutions: Significant throughput increase, optical range improvement and sharing rate increase (capability for more costumers to share the same optical network resource). In addition, optical access networks offer new perspectives for a global optimisation of the fixed mobile-infrastructure by serving as convergence layer for different first mile technologies.

- Increased fibre capacity in access networks: The steady traffic increase along with fibre scarcity and deployment costs calls for new approaches providing a more efficient usage of the fibre capacity also in optical access networks. These technologies will be based on WDM (Wavelength Division Multiplexing) and rely on various modulation/resource sharing procedures, e.g. OFDM(A), TDM(A), FDM(A) and any combination of these procedures.
- Novel architectures for optical access networks: The long reach capacity of the optical fibre offers to reduce the number of Central Offices, and consequently the capital expenditure and operational costs of the access networks. As an element of infrastructure allowing centralised multi-cell baseband processing, optical access will play an increasing role in improving mobile networks cost and efficiency. An infrastructure sharing between different market players is important to maximise network coverage while minimising the overall investments.
- Novel approaches for control and management: Following the trend of network-assisted virtualisation and pooling of IT functions for security, bandwidth management and content delivery, the optical access and backhaul network needs to become an integral part of a programmable orchestration framework for IT and networking resources. A dynamic optimisation of the Quality of Experience as well as flexibility in support of different wholesale models needs to be addressed.

Optical data centre connectivity

Research on novel data centre architectures is required which make use of optical switching and interconnect technologies, a tighter integration of optical and electronic functions, a more programmatic fabric control, and a flexible allocation of networking functions to orchestrate resources elastically and at scale.

- Higher capacity data centre interconnects: Tb/s optical interconnects for inter- and intra-data centre connectivity are required to keep pace with the massive traffic growth in data centre networks. They need to exploit wavelength, space & modulation domains to deliver extremely cost-effective, energy effective and compact solutions for short to medium distances (up to a few km inside the data centre to around 100km between adjacent data centres).Novel data centre network architectures: Scaling data centre fabrics to provide a large cross-sectional bandwidth while at the same time reducing the interconnects requirements is a massive problem. Employing optical switching and interconnect technologies new distributed data centre fabric architectures can be designed which complement the switching of fine granular flows by providing large pipes for the transport of bulk data between different data centre pods or servers.
- New control paradigms: Introducing optical transport technologies for intra- and inter-data centre connectivity increases the number of network layers which need to be controlled. The development of appropriate control paradigms (as currently been investigated in the optical transport group in the Open Networking Foundation for example) as well as their integration into emerging software frameworks for network virtualisation and IT & network resource orchestration is therefore required.

Associated KPI (may be functional if cannot be quantified) <mark>to be defined</mark>.

2.1.1.3   Automated Network Organisation - Network Management and Automation

Problem description

The Operation and Management (OAM) of the wireless mobile network infrastructure plays an important role in addressing these challenges in terms of constant performance optimisation, fast failure recovery, and fast adaptations to changes in network loads, architecture, infrastructure and technology. Self Organising Networks (SON) are the first step towards the automation of (mobile) networks OAM tasks, introducing closed control loop functions dedicated to self-configuration, self-optimisation, and self-healing. The tendency introduced with SON is to enable system OAM at local level as much as possible: The OAM systems are getting more and more decentralised. The long-lasting dilemma has thus been on finding a right balance between centralised control versus distributed SON. However, first generation SON functions need to be individually configured and supervised by a human operator. This manual configuration and tuning is getting less and less practical, due to the increasing complexity of the SON system, since multiple SON functions being operated in parallel may have interdependencies, and lead to network performance degradations due to inconsistent or conflicting configuration.

The objectives for solving the problem

CR networks describe a radio network that employs a cognitive process (i.e., involving thinking, reasoning and remembering) and learning capabilities in order to achieve end-to-end goals. This applies to both the horizontal network (i.e., including all the protocol stack of wireless networks, both radio access and backhaul/transport) and the vertical management views (i.e., abstracting network elements and their configuration towards a holistic high-level view). Control loops need to work not only for single independent functions, but also to be extended for the complete environment to be managed, which may involve several layers of control loops. The control loop diagnosis and decision making processes need to be adapted automatically by learning, e.g. based on the results of previous actions, in order to improve their effectiveness and efficiency, leading to a cognitive processes driven and controlled through high-level operator goals.

The associated research

Advanced intelligence should be developed for realising CR networks. The intelligence of a CR network requires research work:

- For yielding capabilities for the perception and reasoning regarding the context of operation, decision-making regarding its creation/maintenance/release, as well as learning regarding the contexts encountered, the decisions taken to handle them, and the alternate ways they could be handled.
- On development/refinements of functional and system architectures, also taking the integration with the overall wireless world into account. In order to complement the architecture work, there needs to be elaboration, and ultimately specification, of control channels for the cooperation of the cognitive management components.
- On Advanced Human Computer Interfaces (HCIs) to define and acquire the high-level business and technology driven operator goals, end-user requirements, and network capabilities.
- On methodologies for the acquisition, analysis and improvement of knowledge representing semantics of operational goals and strategies, network properties, and historic and current network status enabling an automated reasoning for the alignment of different CR networks functionality at runtime.

Extremely automated systems have to follow high-level operator goals regarding network performance and reliability. These systems have to autonomously ensure and control a conflict-free and coordinated operation of multiple SON functions, providing automated control not only at (low-level) SON function level, but also at the high-level network management, network planning and Operations and Support Systems (OSS) level.

Associated KPI (may be functional if cannot be quantified) to be defined.

2.1.1.4 Implementing Convergence Beyond the Access Last Mile

Problem Description

The convergence of the fixed and mobile networks forms the backdrop for upgrades to operator networks. The stake is to offer customers services that use various wired and wireless networks together with the best possible customer experience, while at the same time streamlining and sharing fixed and mobile network infrastructures and equipment.

Making fixed and mobile networks converge is far more difficult than it might seem, as these networks developed independently of each other and are based on different technologies and protocols. A certain degree of convergence is emerging alongside the boom in IP-based services, as well as through the introduction of a service control layer such as IMS (IP Multimedia Subsystem). It is believed that the convergence of fixed and mobile networks will take years and will require fundamental work on network architecture, technologies and protocols, the shared work of standardisation groups (e.g. 3GPP and BBF) and developments in the regulation and organisation of operators.

The objectives for solving the problem

We propose that the PPP conduct in-depth investigations into two concrete approaches of fixed and mobile network convergence:

- Functional convergence, or the convergence of the functions of fixed and mobile networks: The goal is to better distribute the various functions of fixed and mobile networks by distinguishing those that should be more "centralised" from those that should be more "distributed".
- Structural convergence, or the convergence of fixed and mobile network equipment and infrastructures: The goal here is to share as much as possible the infrastructures (e.g. cables and civil engineering, cabinets, sites, buildings) and equipment of the fixed and mobile networks by envisaging, where possible and relevant, infrastructures and equipment that are shared between these two types of network.

Functional convergence will benefit the customer by making the service independent of the access technology and the device, not through an additional service control layer but by using natively convergent technologies and protocols in the network domain. Functional convergence should also give the customer the best access to the network for a given service and in a transparent manner.

The ability to support new usages such as audiovisual content consumption is also a significant driver of fixed-mobile convergence. Thanks to an improved distribution of the key functionalities of fixed and mobile networks and the flexibility of use of the access interfaces available, functional convergence will enable shorter service access times and allow easier support of growth in traffic and developments in usages. Other expected advantages include the simplification of Authentication, Authorisation, and Accounting (AAA) functions and an intrinsic improvement in availability. For operators, functional convergence will enable easier differentiation of the products and services offered to customers, because the technical obstacles and constraints associated with service-specific networks will disappear. This will have a positive impact on quality of service and quality of experience for the customer (coverage, accessibility, latency and usability).

Structural convergence is probably more complex to implement, as it involves sharing the infrastructures and equipment of fixed and mobile networks. It is expected to enable new mobile front-haul and backhaul architectures in complete synergy with fixed access networks. These architectures will pave the way to the Cloud Radio Access Network (Cloud RAN) concept and could also eventually enable the sharing of fibre access infrastructures or even shared fixed and mobile equipment.

The associated research to be defined.

Associated KPI (may be functional if cannot be quantified) <mark>to be defined.</mark>

2.1.2 Re-Designing the Network

Today, the key players in the application and content delivery ecosystem, e.g., Cloud providers, CDNs, OCHs, data-centres and content sharing websites such as Google and Facebook which often have direct peerings with Internet Service Providers or are co-located within ISPs. Application and content delivery providers rely on massively distributed architectures based on data centres to deliver their content to the users. Therefore, the Internet structure is not as strongly hierarchical as it used to be. These fundamental changes in application and content delivery and Internet structure have deep implications on how the Internet will look like in the future.

What we observe today is a convergence of applications/content and network infrastructure that questions a model of the Internet that used to separate two stakeholders: Application/content infrastructures on the one side and a dumb transport network on the other. One way to go is to enable the different stakeholders to work together, e.g., enable ISPs to collaborate with application/content providers. This can be achieved for example by exploiting the diversity in content location to ensure that ISP's network engineering is not made obsolete by content provider decisions or the other way around. Another option in which we believe is to leverage the flexibility in network virtualisation and making their infrastructure much more adaptive than today's static provisioning.

2.1.2.1 Information Centric Networks

Problem description

The Internet success has changed the way we work, learn and play. The Internet architecture, designed in the 60s-70s, is nowadays facing complexity every day to sustain the traffic growth that never stops and to be usable from various terminals (smart phones, tablets, video game consoles, networked home devices), using various link layer technologies (FTTH, xDSL, Satellite, DWDM, WiFi, 3G, 4G), and for the numerous applications available to the end users (TV, VoD, e-commerce, social networks). The Internet protocol (TCP/IP) is currently coping with some of its fundamental limitations by deploying architectural fixes (mobility, security, multicasting, NAT, etc.) - affixing themselves to an unmoving architecture - which may serve a valuable short-term purpose, but significantly impair the long-term flexibility, reliability, and manageability of the Internet.

The objectives for solving the problem

The mismatch between the current Internet usage and its original design is thus pushing for a radical communication model change, centred on information access. Information-Centric Networking (ICN) is a novel network architecture consisting of communications that revolve around the production, consumption and transformation of information matching user interest. As there was a shift from circuit-switched networks to packet-switched networks, reminiscent of the revolution from the telephony era towards the computer communication era, ICN pushes many design principles coming from the Web directly into the network infrastructure by centring the architecture on "what" is relevant to the user and not on the "network's where" (the customer simply wants to access the desired object wherever it is). The model then changes from a host-based one to an information-based model, where the naming of objects takes a critical role for publication, retrieval and routing.

ICN aims at transforming the current communication model (the classical OSI/IP reference model) into a simplified and generic one so as to avoid all the patches and intermediates layers that have been progressively included, adding complexity and decreasing network performance. ICN is a connectionless, receiver-driven model, where user requests are expressed by an interest for a given object, routed in the network based on its name toward a node having or processing it, and where the related data is sent back along the reverse path, with the possibility for

intermediate nodes to cache the object. Thanks to its design, the ICN communication model allows built-in native features aiming at optimising and simplifying future content delivery architecture, while leveraging service providers' infrastructure capabilities, such as:

- Multicasting: Interests for a same object from different users will be processed in the network as the same interest, thus requested only once, leading to a network optimisation in the delivery.
- User mobility: There are no established connections, thus the user can move, and every interest packet sent by her from her location will be independently processed by the network.
- Multipath: Interests messages can be sent to multiple interfaces in order to share load and optimise the delivery.
- Security, content protection and authentication: Via encrypted and self-certified named objects.
- Caching: Objects can be cached in the network, along the reverse path, so as to be able to deliver them more rapidly in case of subsequent request by other users.

ICN includes storage and execution capabilities, in addition to transport resources, making the network evolve from a dumb pipe transport network towards an added-value intelligent network.
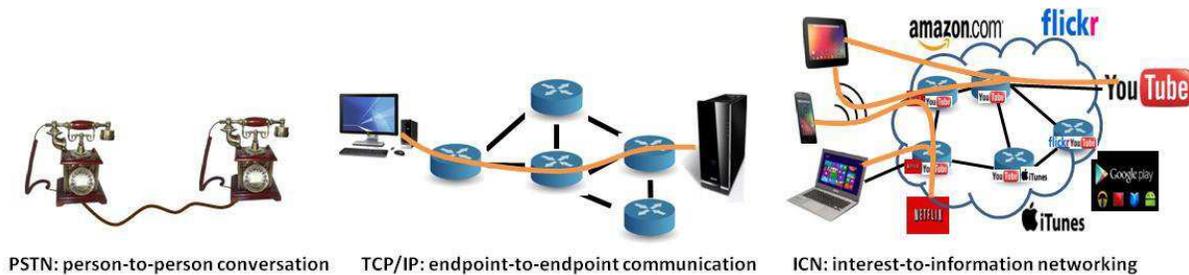

PSTN: person-to-person conversation   TCP/IP: endpoint-to-endpoint communication   ICN: interest-to-information networking
Figure 3: Information Centric Networks (ICN) Perspective

The associated research
- Naming scheme.
- Integration of storage capacities of end devices into ICN.
- Distribution of storage across all routers.
- Elaboration of performing content routing algorithms.
- Interoperability (as easily than with IP).
- Tools and model for measuring the performance.

2.1.2.2   Network Function Virtualisation

The white paper[1] of the ETSI Industry Specification Group NFV provides an excellent description of the problem area which network function virtualisation is going to provide a solution for. In addition, it provides also a comprehensive list of related challenges which are understood as areas where research is still needed. Therefore, this section includes text and figures that are directly taken from the white paper. The following text is too a significant extend based on this white paper.

Problem description
Today's networks are populated with a large and increasing variety of proprietary hardware appliances. Launching a new network service often requires yet another variety of appliance increasing the overall complexity of the network and causing a number of issues. For example finding the space and power to accommodate these appliances is becoming increasingly difficult

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[1] http://portal.etsi.org/NFV/NFV_White_Paper.pdf

and costly in terms of power consumption and capital investment challenges. The rarity of skills necessary to design, integrate and operate increasingly complex hardware-based appliances poses another challenge.

Moreover, hardware-based appliances rapidly reach their end of life, requiring much of the procure design- integrate-deploy cycle to be repeated with little or no revenue benefit. Worse, hardware lifecycles are becoming shorter as technology and services innovation accelerates, inhibiting the roll out of new revenue earning network services and constraining innovation in an increasingly network-centric connected world.

The objectives for solving the problem
Network Functions Virtualisation aims to address these problems by leveraging standard IT virtualisation technology to consolidate many network equipment types onto industry standard high volume servers, switches and storage, which could be located in data centres, network nodes and in the end user premises. We believe Network Functions Virtualisation is applicable to any data plane packet processing and control plane function in fixed and mobile network infrastructures.
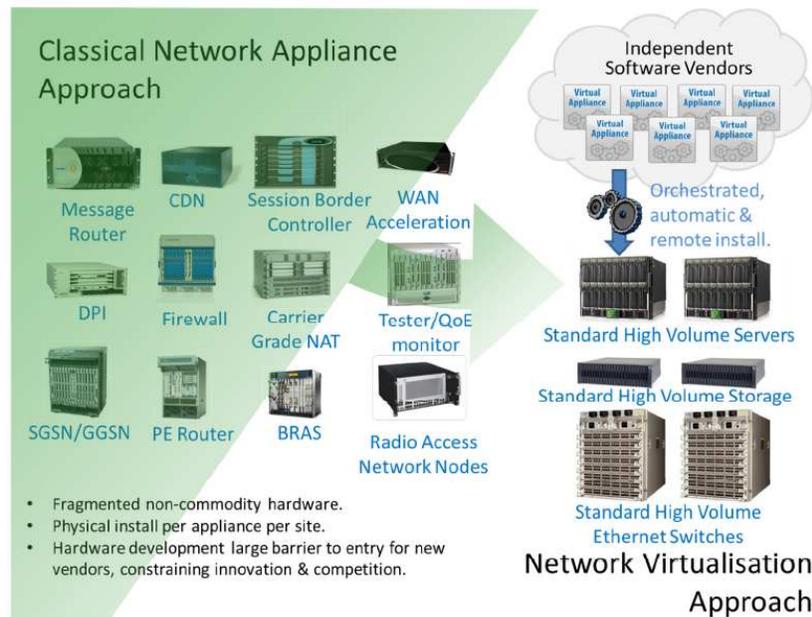

Figure 4: Network Functions Virtualisation

The associated research
There are a number of challenges to implement Network Functions Virtualisation which need to be addressed by the community interested in accelerating progress.

Portability/Interoperability
Network functions virtualisation requires the ability to load and execute virtual appliances in different but standardised data centre environments, provided by different vendors for different operators. The challenge is to define a unified interface which clearly decouples the software instances from the underlying hardware, as represented by virtual machines and their hypervisors. Portability and Interoperability is very important as it creates different ecosystems for virtual appliance vendors and data centre vendors, while both ecosystems are clearly coupled and depend on each other. Portability also allows the operator the freedom to optimise the location and required resources of the virtual appliances without constraints.

Performance Trade-Off
Since the Network Functions Virtualisation approach is based on industry standard hardware (i.e. avoiding proprietary hardware such as acceleration engines) a probable decrease in performance

has to be taken into account. The challenge is how to keep the performance degradation as small as possible by using appropriate hypervisors and modern software technologies, so that the effects on latency, throughput and processing overhead are minimised. The available performance of the underlying platform needs to be clearly indicated, so that virtual appliances know what they can get from the hardware.

Migration and co-existence of legacy & compatibility with existing platforms
Implementations of Network Functions Virtualisation must co-exist with network operators' legacy network equipment and be compatible with their existing Element Management Systems, Network Management Systems, OSS and BSS, and potentially existing IT orchestration systems if Network Functions Virtualisation orchestration and IT orchestration are to converge. The Network Functions Virtualisation architecture must support a migration path from today's proprietary physical network appliance based solutions to more open standards based virtual network appliance solutions. In other words, Network Functions Virtualisation must work in a hybrid network composed of classical physical network appliances and virtual network appliances. Virtual appliances must therefore use existing North Bound Interfaces (for management & control) and interwork with physical appliances implementing the same functions.

Management and Orchestration
A consistent management and orchestration architecture is required. Network Functions Virtualisation presents an opportunity, through the flexibility afforded by software network appliances operating in an open and standardised infrastructure, to rapidly align management and orchestration North Bound Interfaces to well defined standards and abstract specifications. This will greatly reduce the cost and time to integrate new virtual appliances into a network operator's operating environment. Software Defined Networking (SDN) further extends this to streamlining the integration of packet and optical switches into the system e.g. a virtual appliance or Network Functions Virtualisation orchestration system may control the forwarding behaviours of physical switches using SDN.

Automation
Network Functions Virtualisation will only scale if all of the functions can be automated. Automation of process is paramount to success.

Security & Resilience
Network operators need to be assured that the security, resilience and availability of their networks are not impaired when virtualised network functions are introduced. Our initial expectations are that Network Functions Virtualisation improves network resilience and availability by allowing network functions to be recreated on demand after a failure. A virtual appliance should be as secure as a physical appliance if the infrastructure, especially the hypervisor and its configuration, is secure. Network operators will be seeking tools to control and verify hypervisor configurations. They will also require security certified hypervisors and virtual appliances.

Network Stability
Ensuring stability of the network is not impacted when managing and orchestrating a large number of virtual appliances between different hardware vendors and hypervisors. This is particularly important when, for example, virtual functions are relocated, or during re-configuration events (e.g. due to hardware and software failures) or due to cyber-attack. This challenge is not unique to Network Functions Virtualisation. Potential instability might also occur in current networks, depending on unwanted combinations of diverse control and optimisation mechanisms, for example acting on either the underlying transport network or on the higher layers' components (e.g. flow admission control, congestion control, dynamic routing and allocations, etc.). It should be noted that occurrence of network instability may have primary effects, such as jeopardising, even dramatically, performance parameters or compromising an optimised use of resources. Mechanisms capable of ensuring network stability will add further benefits to Network Functions Virtualisation.

Simplicity
Ensuring that virtualised network platforms will be simpler to operate than those that exist today. A significant and topical focus for network operators is simplification of the plethora of complex network platforms and support systems which have evolved over decades of network technology evolution, while maintaining continuity to support important revenue generating services. It is important to avoid trading one set of operational headaches for a different but equally intractable set of operational headaches.

Integration
Seamless integration of multiple virtual appliances onto existing industry standard high volume servers and hypervisors is a key challenge for Network Functions Virtualisation. Network operators need to be able to "mix & match" servers from different vendors, hypervisors from different vendors and virtual appliances from different vendors without incurring significant integration costs and avoiding lock-in. The ecosystem must offer integration services and maintenance and third-party support; it must be possible to resolve integration issues between several parties. The ecosystem will require mechanisms to validate new Network Functions Virtualisation products. Tools must be identified and/or created to address these issues.

2.1.2.3   Software Defined Networking
Problem description
Today packet networks are built on the paradigm of a fully distributed control plane architecture, where part of the intelligence rests in each of the network elements. These network elements (e.g. routers and switches) are "all-in-one boxes", where control and forwarding plane is vertically and tightly integrated, and which can be configured and operated mostly via vendor-specific interfaces only. For example, the introduction of new network services requiring changes in the underlying packet network infrastructure in order to guarantee a certain service behaviour is a highly complex, error-prone, and time consuming task because it requires configuration and operation of individual network elements via many different and proprietary interfaces. Thus, configuration and operation of the whole network is becoming increasingly complex and inefficient.

Software Defined Networking (SDN) is considered to provide significant improvements on the issues described above and to offer further advantages especially in combination with network virtualisation and cloud technologies. The SDN concept is based on the separation of control and forwarding plane of a network, on a logically centralised control of network resources, and on providing an open/standardised (northbound) controller interface offering the opportunity to add network applications in a programmatic way on top of the control entity. By that, SDN is providing access to the forwarding plane via well-defined interfaces and the centralised control and monitoring of the relevant network resources allow a global network view facilitating for instance an optimised problem resolution and simplified provisioning of network resources. The open APIs provide a more high-level and abstract access to network resources and enable the programmability and adaptability of network functions. Especially these APIs are considered to provide a platform for a whole innovation ecosystem: network services will be implemented by programming instead of re-architecting the network and new network features can be introduced at significantly shorter time.

SDN is seen as highly complementary to Network Function Virtualisation and cloud computing. SDN allows to request network resources in a similar way as cloud computing allows on-demand requests for storage and computing power. The combination of these technologies – SDN, virtualisation and cloud technologies – results into the concept of a network operating system that allows unified orchestration of computing, storage, as well as networking resources in a programmable way.

Standardisation of SDN has already started (e.g. OpenFlow and OpenFlow-Config are standardised in Open Networking Foundation, or FORCES in IETF) and SDN is going to be adopted

broadly in data centres. However, applying SDN also to carrier networks will still take time and will require very likely further evolvement of today's SDN technologies.

The objectives for solving the problem
Launching activities on the following research priorities will support the adoption of SDN in telco networks, will help to enable a combined control of telco and IT networks and to leverage advantages offered by SDN in terms of flexibility and efficiency. It is expected that this research will open up a whole innovation eco-system by transforming today's networks into a flexible and versatile infrastructure and in particular by providing open and standardised interfaces and platforms.

The associated research
- Applying and further developing SDN concepts at network infrastructure level. This includes the introduction of SDN into carrier networks (mobile and fixed), the exploration of use cases leveraging the benefits of SDN (e.g. sharing of network resources, disaster handling, or fast introduction and testing of new network features), and the support of and interworking with network virtualisation abstracting from the physical network entities.
- Advance standardised and open approaches for implementing Software Defined Infrastructures, including computing, storage and especially network resources, and its integration into telco cloud infrastructures. This includes in particular exploring the design alternatives of a Network Operation System (NetworkOS) able to provide an orchestrated and unified access to computing, storage and network resources. Design alternatives could range from a fully integrated execution environment to a set of separate resource services leaving the integration role up to the user/applications. The design could also comprise layers such as a kernel able to integrate and orchestrate any combination of storage, network and computation facilities, and a service layer on top of the kernel that offers a set of resource service primitives to applications.
- Develop concepts and mechanisms ensuring that the NetworkOS meets carrier-grade requirements such as performance and reliability; special emphasis should be given to security protecting the NetworkOS functions as well as the data manipulated by the NetworkOS.
- Develop a common information model describing the interfaces and operation models for all the resources that should be integrated and orchestrated within the NetworkOS – this will allow for a multi-vendor environment.
- Provide a development framework which will allow the creation of a rich set of new resources services with new SLAs taking advantages of the intelligence available in the centralised control knowing for example about the real resource distribution and performance and promote this development framework to an Open Source environment.

Associated KPI (may be functional if cannot be quantified) to be defined.
- Number of reference implementations of a NetworkOS
- Availability of standards supporting the concept of a NetworkOS

2.1.2.4 Networks of Clouds
Problem description
One future challenge will be to guarantee and continuously improve customer experience offered by cloud-based services. Such experience relies on the End-to-End QoS, and more generally on respective SLAs in place for a given service. This includes well-known characteristics, such as latency, throughput, availability, and security, but by adopting the principles of Clouds, also elasticity, on-demand availability, lead- and disposal times, multi-tenancy, resilience, recovery, and similar characteristics important especially in case of cloud-based services. However, in order to guarantee this kind of service level, network-based service qualities may not be enough, but need to be aligned with platform-level and Cloud specific tenets, like dynamic discovery, replication, and on-demand sizing of VMs, since previous over-

provisioning best-practices inherent to hosted and managed execution environments are no longer applicable.

Furthermore, in the future, there will be many Cloud-derivatives offering different approaches and levels of QoS support. Moreover, public, private and hybrid clouds and respective infrastructure, platform, and software services are frequently compositions of many components (services) spread across many horizontal and vertical domains (e.g., different provider, network, data centre, and service-platform domains). This will inevitably result in complex multi-domain scenarios, in which logical Clouds are formed by federating different infrastructure or platform clouds and complex service compositions at application level. Obviously, such a highly-distributed environment requires reliable and capable connectivity and the ultimate customer experience depends on the performance of the overall (composite) service.

The objectives for solving the problem
Advanced QoS support of cloud based services and applications within federated cloud scenarios: In order to meet these multi-faceted and interconnected challenges, future research should address network support for accessing and inter-connecting complex multi-domain Cloud services. In particular the nature of on-demand, distributed, service-oriented, applications run on top of clouds need to be better understood and respective metrics must be defined.
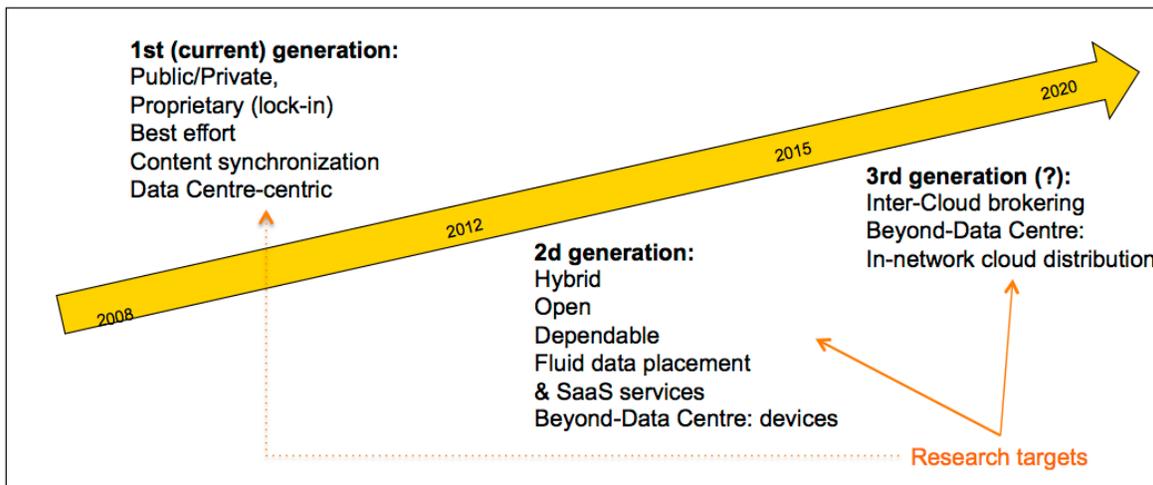

Figure 5: Networks of Clouds

The associated research
Some initial directions would be the autonomous self-optimisation of service orchestrations, based on the traffic matrixes of such multi-service composite applications, and information about the capabilities and status of the underlying connectivity infrastructure. Such research should be supported by exploration of network traffic characteristics generated by multi-service compositions. Especially the IoT-Cloud combination may pose novel requirements and high demands on networks by firstly, massive amounts of information exchanged between the IoT domain and one-or many Clouds and secondly, the huge networks that may be very dynamic in nature in particular in the IoT space.

The associated KPI that measures (may be functional if cannot be quantified).
- Number of services with demanding QoS requirements running in hybrid cloud environments.
- Availability of standards supporting QoS in hybrid cloud environments.

2.1.3 Ensuring Availability, Robustness and Security

Problem description

Telecommunications networks have traditionally been accompanied by a good reputation regarding the technical confidence. Time for the exclusive use of these networks for telephony, "five nines" were the norm: an availability of 99.999%, equivalent to about 5 minutes of downtime annually, was naturally required.

With the explosion of the Internet and IP, whole sectors of the economy have shifted their networks dedicated to the common infrastructure operators. The "critical services" have left the narrow frame of emergency numbers to include other telecommunications services: Medical information, financial data… The unavailability of these services, due to a bad design, an accident or a malicious act, can then be catastrophic.

The ever stronger customers requirements in terms of service availability, security, confidentiality of personal data will put many constraints on infrastructure (networks, platforms), but will also be opportunities for operators who will be the meet these requirements.

It is essential in this context to reconsider the robustness and security services, and more specifically, critical services.

In 2020, infrastructures and services infrastructures will be based on massive abstractions or virtualisation technologies (for instance, cloud services to be used by all sectors such as energy, health, or telecommunication, or virtualisation of networks infrastructures). It means that the point on which service or content could be delivered will be operated over several heterogeneous infrastructures which could be managed by several independent entities. Improvements in terms of scalability, dependability, service quality and security in the broader sense will be required in order to consider end to end SSLA (Services and Security Level Agreement) as a basic for service delivery.

The objectives for solving the problem

The increasing evolution in IT networks brings lots of new vulnerabilities to networks and related online services, and the challenges in network protection, management, modelling and designing for future networks. Security in existing and Future Networks (i.e. Future Internet) is a subject that continues to receive a lot of attention from research and industrial communities, especially due to the fact that Future Networks must exhibit various in-built security mechanisms. The other aspect that is becoming increasingly important in the design of Future Networks, including in the evolving networks, is that of Modelling and associated Tools, since models are increasingly becoming important both in network design and for guiding the operation of networks e.g. Federation Models, etc. The implementation of network security, management, modelling and tools in evolving networks helps to realise the self-* management (self-configuration, self-healing, self-optimisation and self-protection), proactive, autonomic, controllable management for future IT networks.

The associated research

Security Level Agreement
- Provide methods and schemes to compose different and heterogeneous SLA commitments and provide the End to End resulted SLA.
- Develop mechanisms to allow whatever services or applications to evaluate local and contextual Security Level Agreement. Develop mechanism to allow a service to commit to be used over a software layers or operating system claiming that they have not been altered since their deployment (each service is able to know/be aware of the contextual chain of liability before be used in some environment).

Network security and integrity
- Develop end to end security models (risks and threats propagation between heterogeneous infrastructures or platforms, system of systems), new cryptographic technologies (low CPU and low cost), and context-based security models.
- Develop cyber security mechanisms for the detection of abnormal events (behaviour analysis, weak signals, analysis of heterogeneous information from multiple sources, collect of each incident of every stack composing a production line …), observation of attack patterns and dynamic creation of countermeasures stopping attack proliferation (adaptive security); Deep Intrusion detection (on application layers) user-centric and not only "system"-centric; Adaptive cyber security mechanisms able to dynamically take into account contextual security objectives of a network that is only partially known (through observation of traffic point).
- Establish provable security development techniques that help reduce risk and protect organisations in the ever-changing technology landscape (in particular for complex system of systems).
- Develop mechanisms to allow the secure deployment of counter measures (in a provable way) over a specific service, platform or infrastructures. The activation of a specific countermeasure may induce a direct impact on the corresponding SLA.

Network Data Analytics
Operating and managing the networks is based on data such as configuration and log files, alarms etc. Conventional technologies, tools and approaches are still able to process the data required for most of the use cases in today's networks. However, as soon as more demanding cases need to be supported, such as predicting some network failures, the collection and processing of network data over a longer time period becomes indispensable. The combination of network data with data from other sources such as census data, social data or geographical information has also a certain potential. In such cases, the size and variety of the data becomes the problem and conventional technology is not any more capable to deal with acceptable response times and costs.

Therefore, big data technology is needed in order to realise some advanced use cases in today's networks and will be certainly required in future communication networks. We can group the use cases relying on big data into three main categories:
- Managing and operating networks and gaining insights into the network with the goal to improve the network quality.
- Gaining insights about the subscribers and their behaviour in using the network with the goal to improve the customer experience.
- Develop totally new cases with the goal to offer new business opportunities for a network operator in selected industrial sectors.

The first category includes for example, isolation and correlation of faults within the network, support of security related detection and prevention mechanisms, traffic planning, prediction of hardware maintenance, or the calculation of drop call probability. The second category comprises use cases such as fraud detection, customer segmentation, support of marketing campaigns, or churn prediction and analysis. The last category covers those use cases and services that a network operator can sell as an additional business opportunity. These uses cases will combine typically network data with for example social or geographical data and resulting services are for instance social interaction graphs, traffic jam detection, mobility analysis or disaster detection. Operators can also offer access to network data controlled via a Platform as a Service (PaaS) and thus they can provide the basis for an ecosystem in which innovative services can be created by having the access to those data.

For all the above categories, big data technology will allow to collect, store, retrieve, process, analyse and visualise huge amount of data and will help to identify new use cases that are hidden in this data.

To achieve this objective the following specific research priorities are proposed:
- Improve quality of Big Data: Create models for improving data quality and introduce data quality models to streaming and batch-oriented Big Data tools to provide better insight on the behaviour of networks – e.g. down-sampling data or throwing away low quality data.
- Speed up the process of analysing network data: Integrate distributed machine learning algorithms on top of Big Data tools.
- Apply big data technology in order to understand and model the behaviour of mobile networks in order to optimise the network and to gain insight into their users.

Associated KPI (may be functional if cannot be quantified) to be defined.

2.1.4 Ensuring Capable End-user Devices and High Amount of Other Connected Devices
To be defined.

First example of challenge. Other challenges to be developed.

Building an Information-aware Future Internet - A Laboratory for new Network Infrastructure Experimentation
The Internet architecture is reaching its limits due to the constantly increasing number of "connected" mobile devices that has pushed Information production and consumption at unprecedented levels. The current global network infrastructure has been able to sustain user demands until now but its capacity and capabilities are limited. Moreover, it is clear that boosting the network capacity is not enough and moving processing outside of the network (e.g. in data-centres) does not reduce traffic load. The solution is to make a smarter network that better understands what to do with the content it transports, rather than numbly perceiving it as undifferentiated stream of bits and bytes. In the research community there is a shared belief that the network has to become more aware of the information it carries for in order to have:
- More efficient and differentiated delivery.
- More efficient management of network resources (bandwidth, storage, computing).
- Native support of new services.
- Reduction of transport cost /carbon footprint.

The main objective of the challenge would be the development of a blueprint of a future Internet network and a testbed platform for the interconnection of information-aware equipments. The phases of the program will be:
- Architecture and testbed specifications design (collaborative work of a core set of partners)
  - Design of basic information-aware functions: Packet format, naming structure, integration with IP.
  - Demonstration at small scale of test-bed functionalities.
- Testbed setup
  - Define equipments requirements and develop tools for node programmability.
  - Design of resources reservation tools, slicing and virtual network creation tools.
  - Setup of large scale European test-bed interconnected via IP legacy network and test utilisation.
- Experimentation, Application development, Global Proof of Concept
  - Test of new services: application and tailored protocol stack development on top of predefined information aware API.
  - SDN control plane definition and SDN experimentation.
  - Monitoring and management tools for Information-aware networks.
  - Quantify benefits of new approach over existing solutions via experiments.

The proposed testbed will be composed of two different types of nodes: In-network nodes and end-user devices (i.e. Fixed nodes and Mobile devices). For In-network nodes two different types of equipments can be identified. The first type is a proprietary/standard-based telecom equipment, with the advantage that it will have significant I/O capacity and low level programmability but will be expensive, with limited number of suppliers and ad-hoc expertise. The second solution is a motherboard-based in-network equipment that contrarily to the proprietary solution, will be much less expensive, with a large number of suppliers but with limited I/O capacity and low level programmability not supported.

The test-bed developed during the project will be programmable:
- At Application layer, allowing test-bed users to easily deploy and test new applications. Allows users to redirect real traffic over the test-bed.
- At Network layer mechanisms, allowing test-bed users to program end-device and in-network nodes to run new network layer mechanisms.
- At Lower level network primitives. This part is not exposed to users. Only the owner of the equipment (or a third party through an agreement) can modify the basic communication primitives and algorithms.

The test-bed construction, will involve different actors:
- Equipment Vendors: Interconnection to the test-bed of end-user devices/ proprietary solutions for information aware routing/switching, potential interest in protocol stack and API definition, hardware/software algorithm programmability.
- Content/Service Providers: Comparison of native network embedded and application-layer solution in terms of content/caches management, algorithm programmability for optimised content delivery, quantification of performance benefits for end-users.
- ISPs/Carriers/Network Operators: Test of new services exploiting content awareness, quantification of transport and management cost reduction with respect to dedicated application-layer overlays, quantification of gains for in-network processing of information with respect to cloud solutions, design of network management tools leveraging on information awareness and SDN/software control.
- Research Centres/Universities: All of above, most architecture and protocol design and experimentation for information-aware networks at large scale.

2.2   Key Stakeholders along the Value Chain

This sub-section addresses the key stakeholders along the value chain (research, innovation, exploitation, usage).

2.3   Indicative Timeline and Estimated Budget

This sub-section addresses the first Industry Core Group perspectives on timeline and estimated budget.

3. Expected Impacts

This section describes first the industry commitments to implement the multiannual roadmap, then the expected impacts of the PPP and strategic objectives and the ability to leverage additional investments in research and innovation. Follows the strategy and methodology/mechanism for coordinating the implementation and measuring progress in R&I activities to ensure objectives are met, the identified indicators and the proposed methodology for monitoring industrial commitments.

3.1 Description of Industry Commitments

This sub-section describes the industry commitments to implement the multiannual roadmap (including estimated scale of resources), and to exploitation of results.

3.2 Expected Impacts of the PPP and Strategic Objectives

This sub-section details the expected impacts of the PPP and strategic objectives (e.g. impact on industrial competitiveness including economic, socio-economic and environmental impacts, and other effects).

3.3 Ability to Leverage Additional Investments

This sub-section addresses the ability from PPP stakeholders to leverage additional investments in research and innovation.

3.4 Strategy and Methodology/Mechanism for Coordinating the Implementation and Measuring Progress

This sub-section is describing the strategy and methodology/mechanism for coordinating the implementation and measuring progress in R&I activities to ensure objectives are met.

3.5 Identified Indicators

This sub-section details the identified indicators (e.g. progress, investment, efficiency of implementation, outcomes).

3.6 Proposed Methodology for Monitoring Industrial Commitments

4. Governance

This section describes first the governance model of the partnership, including its decision making processes and the means to ensure openness, transparency and fair representation of all stakeholders, then the principles regarding the sharing of information, and dissemination of results and handling of IPR benefits of the sector, in compliance with H2020 Rules of Participation, and finally the Association statutes and modus operandi of association.

4.1 Description of the Governance Model of the Partnership

This sub-section describes the governance model of the partnership including its decision making processes and the means to ensure openness, transparency and fair representation of all stakeholders.

4.2 Principles Regarding the Sharing of Information and Dissemination of Results and Handling of IPR benefits of the Sector

This sub-section describes the principles regarding the sharing of information, and dissemination of results and handling of IPR benefits of the sector, in compliance with H 2020 RoP.

4.3 Association Statutes and Modus Operandi of Association

This sub-section describes the association and its related organisation.

List of Acronyms

API	Application Programming Interface
ARPU	Average Revenue per User
CAPEX	Capital Expenditure
COTS	Commercial Off The Shelf
CR	Cognitive Radio
EC	European Commission
EEA	European Economic Area
ETP	European Technology Platform
EU	European Union
FDN	Fibre Distribution Network
FP7	Framework Program 7
GDP	Gross Domestic Product
H2020	Horizon 2020
HCI	Human Computer Interface
ICT	Information and Communication Technologies
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technologies
ITU	International Telecommunications Union
LTE	Long Term Evolution
LTE-A	Long Term Evolution – Advanced
M2M	Machine to Machine
NGN	Next Generation Networks
OAM	Operation, Administration and Maintenance Operation and Management
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operational Expenditure
OSS	Operations and Support Systems
PaaS	Platform as a Service
PC	Personal Computer
PON	Passive Optical Network
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research & Development
RAN	Radio Access Network
RAT	Radio over Fibre
RRM	Radio Resource Management
SDK	Software Development Kit
SLA	Service Level Agreement
SME	Small Medium Enterprise
SON	Self-Organising Networks
SRIA	Strategic Research and Innovation Agenda
TCO	Total Cost of Ownership
TV	Television
UHF	Ultra High Frequencies
UMTS	Universal Mobile Telecommunications System
USA	United States of America
WDM	Wavelength Division Multiplexing

WDMA	Wavelength Division Multiple Access
Wi-Fi	Wireless Fidelity
WRC	World Radio Conference
WWI	Wireless World Initiative

References (All references to be included in the document – References table to completed in version 3.0).

[TBC]   TBC