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Table of Content

TABLE OF CONTENT	4
RATIONALE	5
1 NEW REQUIREMENTS ON FUTURE NETWORKS	6
2 IMPACTS ON FUTURE NETWORKS ARCHITECTURES	7
2.1 Content creation and delivery and Internet of Services	8
2.2 Internet of Things, Real World Internet and 3D Internet	9
3 RESEARCH PRIORITIES	9
3.1 Architecture for Ubiquitous Connectivity and Information Centricity	9
3.2 Resources as a Service with accountability and auditing	12
3.3 Integrating optical networks and high speed wireless	13
3.4 Wireless perspective with a cognitive radio and networking view	15
3.5 Establishment of Situation Awareness in Network Nodes	16
4 RECOMMENDATIONS	18
5 REFERENCES	19

Rationale

After 30 years of mature development, the value of the Internet as a flexible and open structure supporting a wide variety of services and applications, is gradually reaching its limits. This flexibility was built upon often through workarounds and patching whilst preserving its architecture, protocols and end-to-end principle with added mobility, security and quality of service (e.g., CIRD, NAT, Mobile IP, NEMO, Multi-homing, IPsec, IKE ...). Worldwide, several activities try to provide answers and new solutions to current and future Internet challenges, including both services and flexible business models. Examples are the USA Global Environment for Network Innovations (GENI), the European Future Internet Research and Experimentation (FIRE), the European Think Tank (EIFFEL) as well as the recently established European portal on Future Internet Assembly [1] meant to coordinate independent European efforts in Future Networks, and services research and developments.

Problems and challenges for Post-IP and “Future Networks” are well identified and published by the European technology platforms and the European initiatives. The FP7 programme has also funded several large projects addressing the limits and weaknesses of the current Internet (see [2]). There is a commonly shared concern that the current Internet architecture, despite its success and strengths, will not adequately perform in the coming years. At least, not to an extent where billions of information objects, machines, things and subjects are expected to interact in real-time though intermittently. Do so on a secure basis and enjoy reasonable quality over heterogeneous platforms. There are expectations that current Internet performance will slow down unless significant innovations in the European and global research and development communities lead to a post-IP era where the IP protocol suit and current architecture will no longer be the show stoppers to new, innovative and efficient solutions.

Only radical changes at many levels in the architecture can avoid current pitfalls. The need to network billions of information objects and subjects instead of hosts is one key objective of Future Networks. Another key challenge, that will also influence the architecture, is the requirement to efficiently handle dynamics related to the wireless environment and to mobility and facilitate ease of integration between real and digital worlds. This still requires more attention from the research community. Future Networks have to be also sufficiently open to support users in their roles as “prosumers” (content and services producers and consumers) and flexible enough to enable yet unforeseen future business models and interfaces.

The Future Internet architecture will not be mandated exclusively by technical challenges but also by governance, complex societal and environmental concerns. We shall consequently address the Post-IP requirements and challenges by keeping all these key aspects in mind. We will nonetheless explore as a first step the technical facets to identify areas not sufficiently addressed today and take into account new emerging technologies and paradigms with potential impact on Future Networks. The ongoing European research (FP7 program, technology platforms and experimental facilities) foresee a number of underlying paradigms as essential for the Future Internet. The goal pursued by these projects and initiatives is to explore, investigate and consolidate these concepts from different but complementary perspectives of networking, services,

software architectures, and content delivery. These basic functions would then be instantiated, invoked, aggregated, composed into new functions and used autonomously by the systems themselves to reach the required levels of extensibility, flexibility, evolvability and cognition for future networks.

1 New Requirements on Future Networks

A number of European funded projects are advocating several paradigms to address Future Networks challenges and to fulfil already identified requirements. The need to embed mobility, quality of service and security functions in the architecture stands out as a fundamental features and innate capability for future networks. The e.mobility technology platform addresses future networks from a mobile/wireless perspective and puts naturally the focus on the highly dynamic nature of wireless systems and networks. Managing mobility, intermittent connectivity and self-management/configuring/healing do remain key aspects to the approach. Ensuring an identity-locator split to reduce the impact of mobility on the applications is also of paramount importance. Information objects, content, service components, devices and processes should not be tied to hosts as in today's Internet. Objects can migrate to other hosts. Assuming that nodes and things are mobile should be the default assumption whereas fixed nodes are only a special case of mobility. These are the working assumptions for this white paper.

Among Future Networks challenges addressed by the European research community and the majority of EU FP7 projects, the following still require additional investigations:

- Integrated solutions for Security, dynamics and mobility management, quality of service
- Manageability, diagnosis and auditing and user/network accountability
- Availability which requires maintainability and reliability
- Scalability especially of the networking or routing systems
- Extensibility, flexibility and "evolvability" that are yet to be fulfilled in current networks and technologies

- These projects investigate key paradigms foreseen as indispensable to evolve today's Internet. The objective is to consolidate, validate and envisage integration in future networks of vital concepts:
 - Autonomic and self-* system capability with situation and situated awareness
 - In-network management solutions to reduce operation resources, ensuring manageability and Opex reduction
 - Virtualisation of services and network resources
 - Cognition a fundamental enabler for future networks in ensuring autonomous behaviour and smooth (plug and play) integration in the surrounding environment.

The Future Internet will be a:

- Internet of users serving people and communities,
- Internet of Services,
- Internet of Content as well as an Internet of Knowledge,

- Internet of things integrating (real, virtual and digital) worlds and of information objects.

This observation or forecast means that future network architecture(s) and services need to address fundamental requirements and cross discipline/industry cooperation. This will be achieved via an alignment of the IT, Telecommunications and Media spheres. This calls for combining possibly merging concepts to develop new architectures appropriate for networked media such as virtual world, the 3D Internet and the Internet of Things.

Users, in addition to traditional providers, will produce and exchange contents and knowledge. This creates a new context where control is distributed amongst multiple actors with multiple roles capabilities and business interests and size. Future networks have to facilitate the cooperation, the interoperability and the service continuity in this new business and market space. Future networks and services have to be loosely coupled to enable independent evolution of each to new and yet unforeseen applications, services and networking technologies. Current networks are simply too tightly coupled, often vertically integrated, to scale to the billions of software and information objects resulting from this dynamic creation of new content and applications in addition to the billions of physical and virtual objects that will make it into the Internet.

2 Impacts on future networks architectures

The emergence of the Internet of Things, the Internet of Services and the 3D Internet will have direct and major impact on the architecture of future networks. Users will search, find and use objects to create or compose new objects. The objects are building blocs each contributing to the overall service communication experience. Future networks will gradually move to open environments where content, services and infrastructure resources become self-contained with ability to dynamically plug and play. Future networks need to provide the enablers to empower users to design and create their own communications services by selecting the most suitable set of objects for best service delivery and experience.

Over time objects can change, being upgraded and enhanced. They are even likely to mutate gradually to new forms if the environment has sufficiently changed to warrant an evolution. In the long-term objects will be able to plug and play in the surrounding environments and will learn to forget past configuration and environments no longer in use or that have disappeared for the benefit of new ones. Machine to machine communications involving devices, sensors, ad hoc networks will also be the subject of discovery, adaptation and mutation via learning, inference and reasoning. These objects, expected in massive numbers, will have to be networked efficiently, regularly and dynamically to be remotely reached, configured and controlled. These are new requirements that current networks do not fulfil easily, efficiently and trustworthily.

Dynamic and collaborative “services and content” aggregation, bundling or composition poses the same challenges in networking. Components can change, move or migrate, fail, become unavailable. Maintaining connectivity and replacing components by others or equivalent components is a challenge deserving additional attention and research.

Managing and networking things, devices, services or applications and content leads to different requirements since objectives and constraints are different. Developing an information model to identify the basic and core function of future networking and networks architectures will require in fact meta-models and meta-concepts beyond simple metadata and specific models per service or application domain. There is a need to cast the modelling in a more general framework to identify the super set of functions required from networks to support these next generation services. Such a meta-model would lead to a general formalism to design solutions for each domain and realm from a common base. This would hold for the definition of a location-independent naming and addressing paradigm for all kinds of objects. Would facilitate the definition of routing and resolution mechanisms for all types of services, where access to files or handling of communications services or multimedia streams all use the same formalism. One research priority would be to develop such meta-models to ease the description and modelling of information, objects, processes and service components in a way that would facilitate the design of future networks services.

When designing the network of the future, the energy consumption and carbon emissions cost need to be evaluated. The requirements for better energy management and for reduction of the carbon footprint in ICT tend to oppose the highly distributed architecture advocated for future networks. The new internet architecture would use servers, storage and computers co-located at renewable energy sites. In essence, future networks and services architecture must explore how bits and bandwidth are traded for energy saving and lower carbon. .

2.1 Content creation and delivery and Internet of Services

Trends in content creation and delivery put new requirements on the underlying networks in terms of networking for collaborative aggregated multimedia, dissemination, delivery, retrieval and storage. The Future Internet is driven by these demands and can provide key capabilities if it behaves more like a “content network” interconnecting objects rather than byte streams and hosts. A paradigm shift towards connecting information objects and service components or even processes is needed. User generated content is playing a larger role today on the Internet and will continue to grow. Users produce, consume and interact with content and exchange multidirectional flows with traditional actors and other users. Content can be traded, exchanged and auctioned. Semantically annotated content facilitates sharing, searching, using and reusing by treating digital objects according to their semantic closeness instead of relying only on their digital representation as bits. How much of these key functions should be handled and embedded in the network? What should best happen in the content and service management architecture should be the subject of additional research. Is the alternative a rather sufficiently flexible interface? Should coupling between levels be loose enough so the functional split between levels in the architecture becomes itself context based?

The Internet of services views everything as a service. Starting from abstract descriptions of the service, trading and binding functions can search, select and bind these abstract representations to concrete descriptions and execution environments

according to both functional and non-functional service requirements. Network services and networking need to support such an Internet of services by providing a number of key basic functions from the networks to ease this mapping between abstract service descriptions and concrete ones by selecting the most appropriate network resources to deploy and run the services and applications. In this case, future networks provide resources as a service themselves so that applications and services can run smoothly in the most appropriate execution environment or substrate.

Another objective is also to network information objects that include service components, content and processes to ensure extensive data exchange for multimedia streams, P2P and M2M communications while controlling impact on network resources. This is also true of content and services interactions and signalling support needed during the aggregation and composition phases.

2.2 Internet of Things, Real World Internet and 3D Internet

Making real world information directly available to services and applications will lead to networks dominated by connectivity of huge numbers of sensors and actuators to the future Internet. This will have major impact on the architecture in terms of amount of data to exchange and manage. The naming of objects needs to evolve and new naming and addressing schemes developed. An order of “10¹⁶ objects” is foreseen in the Future Internet. These objects need to be stored, searched and accessed transparently. When combined with the 3D Internet and the composition and aggregation of objects for 3D rendering, the complexity and size would become overwhelming with current networking, storage, caching and searching mechanisms. Revising current architectures in depth is unavoidable for the future networks to scale, become manageable and bridge the physical and virtual worlds. As sensors and smart and small devices are deployed in numbers they should simply plug and play into the Internet and achieve symbiosis with applications and services. This is not a simple matter of producing more addresses but rather the challenge of ensuring a split between identity and location while devising knowledge and semantic and identity based networking. In addition to the networking, the systems and networks should withstand the explosion in traffic and management requirements.

3 Research priorities

3.1 Architecture for Ubiquitous Connectivity and Information Centricity

One fundamental requirement for future networks is the identification, definition and specification of a flexible, extensible and evolvable architecture that does not suffer from weaknesses and problems found in the current Internet. The inability to audit and understand the root cause of anomalies and faults in the current internet and networks remain a key hurdle for enterprise interoperability and cooperation. Dynamic peering of

actors and “coopetition” greatly influence the overall architecture. As projects and investigations scramble for solutions, a number of trends and schools of thoughts emerge where each advocates putting more intelligence and capabilities in a given level or set of components. Both evolutionary (e.g. in Trilogy) and revolutionary (in 4WARD) paths towards future networks need to be explored.

There is today no agreement as to where the functional split should be between content and applications level, service architectures and the network level (if one collapses the architecture into few levels and possibly none). No matter the preference and belief, from an architectural standpoint, the reality is: there is no unique, no immutable split. Hence, the ability to plug and play and set up the right split based on context and domains appear as compelling as the “evolvability” requirement. The difficulty is to harness complexity that comes along with adaptability and autonomic configurability and management. Identifying systems that facilitate the dynamic moulding of the architecture to situation should be a research priority.

This research priority is in line with the notion of the mediation bus proposed by e.mobility EG3. The goal is to make this mediation bus completely distributed and transparent with functionality shifting as required from one realm to another, from a level to another without affecting coherence and stability of the overall system. In essence, we want it to mutate, dynamically split and sculpt its constituents to best fit into each level, as needed and break the philosophy that it should not. The challenge of achieving this in a controllable, auditable and reliable way is however daunting. Addressing this challenge is in our view a priority for the European RTD community.

Plans to ensure transition, migration and automatic deployment of new paradigms and processes in networks will also be essential. Evolvability and mutation are once again key features for future networks so the past does not preclude revolution. In the evolutionary scenario, resource and load management and the ability to control or simply manage capacity and energy consuming applications are missing in current networks. In the revolutionary approach, the network architecture needs to be revisited. New paradigms related to embedded and autonomous management, virtualisation of systems and networks resources, advanced and cognitive networking of information objects (be them real, virtual, multimedia or service data objects) need to shape and redefine the overall architecture. The notion of layers or stacks and inter-domain interoperability would become less significant.

Information centric networks providing ubiquitous connectivity to persons and information objects shall be driven by the requirements from new content creation, distribution and dissemination, from services, from the real and virtual world objects and the need for lower carbon footprints. This requires new topologies and architectures.

Another priority is to develop methodologies and tools to assess new architectures as they emerge. This is currently lacking and there should be means to assess conformance to scalability, resilience, robustness and reliability requirements of the new systems. In other words, a research priority is to develop these methodologies and evaluation frameworks to establish proof before deployment. Experimental facilities can here play a key role by enabling this compliance and conformance tests. These platforms are also a natural path for incremental integration, migration and gradual replacement for the Future Internet. Europe should consent additional effort and

research to build these assessment systems. As Future Networks will be complex systems, there is also the added need of understanding emerging properties and harnessing complexity. Modelling, simulation and the development of a “Network Science” should be a primary focus to lay down the fundamentals of networks and networking for years to come. The scientific community should view networks and networking as a discipline.

3.2 Resources as a Service with accountability and auditing

“Resources as a Service” (RaaS) has a rather broad scope and concerns sharing and isolating resources and providing them to other actors. The latter include end users as additional players providing connectivity, awareness and assisting mobility. Providers will nevertheless continue to play an active and major role as they are in a better position to ensure provisioning, control and management of virtualized resources and services. Network and computer resources virtualisation has received much interest lately and is now the focus of EU projects such as 4WARD, FEDERICA and several experimental platforms such OneLab2.

There are consequently two key levels in the RaaS notion or concept: the end user centric case and the scenarios where providers play a more prominent role. These are not mutually exclusive and can be quite complementary. In the end user case, discovery and situation awareness are key elements of the concepts and the context corresponds to some extent to social/community networks where users can sense, discover, learn the environment and services offered by other users on location and adapt their connectivity and interactions with others acting as providers accordingly.

In the larger framework, providers are naturally involved. They deal with the broader principle of virtualisation to provide stability, reliability, control and management. Virtualisation can be used to deploy gradually Future Networks, diversify the Internet and make it as polymorphic as it needs to be.

Virtualisation of computer resources and fixed networks is more mature than virtualisation of wireless resources and spectrum. We believe that priority goes to harnessing virtualisation of wireless resources and to the cooperation of users. The way users can benefit from more traditional providers’ services to ensure a stable and secure environment cognisant of their privacy protection requirements is as important. Ensuring auditing and accountability has always been a challenge and remains a problem. The current Internet is still stateless, masks events within the paths and puts partial knowledge only at the end-points. This amounts to operating in the semi-blind mode, having no clue about root causes and remaining unable to isolate them. This problem will grow when users themselves provide connectivity and services to other users.

No matter the service, the object or the component made available for sharing and for use, auditing and accountability will become even more critical and a central requirement. Before putting anything in the Internet, it should first comply with well-defined policies, rules, and good practices. This area is completely unexplored at this stage by Future Networks Research. There are no mechanisms, tools or methods to check conformance of information objects, service components, processes or software prior to their insertion (or publication) into the Internet. Once these elements are integrated, there are no means to ensure auditing and accountability either. Objects should come not just with functional and non-functional attributes and descriptions but also with auditing and accountability specification and commitments. Embedding these features directly or indirectly into the components provides clues on expected behaviour and guarantees to applications that can more easily select, combine and use them.

From this analysis, it becomes evident that R&D in Europe should focus on designing enablers for better accountability and auditing to distribute responsibilities and reward amongst all the players that contribute to end-user services and applications. This entails the ability to describe various types of resources (from service components all the way to resources such as spectrum with the appropriate levels of abstraction and models in each case) to discover them to begin with but more importantly to extend service architecture principles to the networks. This would promote to the networks the notion of modularisation of components to facilitate dynamic composition and deployment of applications. This will concurrently enable better delivery of these components as well as accountability to know who contributed what to the end user service. This would considerably ease cooperation and compensation based on factual and verifiable contributions.

3.3 Integrating optical networks and high speed wireless

The integration of high-speed wireless and optical networks is one possible response to the growing access bandwidth requirements from high-speed data and video services. Requirements of multi-gigabits/sec per link in both wireless and wired access networks foreseen several years ago continue to grow for emerging interactive 3D Internet and IPTV/HDTV applications. Even environment monitoring and data mining requiring High Performance Computing for analysis, decision making and remote control and management can benefit as well from such super broadband access capabilities. Radio-Over-Fibre (ROF) provides integration of optical and wireless networking systems and a practical solution to handle not only the high capacity requirements but also to enable high mobility management. A number of key emerging paradigms such as OFDM for ROF, Radio-over-free-space-optics provide additional opportunities. The expected advances in wireless technologies need to be coupled with those in optical networks to broaden the integration. A large fraction of the revenues for ICT will come from high speed and interactive multimedia services with next-generation access networks driving the needs for convergence of wireless and wired services to offer users larger choices, simplicity and convenience. Occupancy of lower frequencies in the 2 to 66 GHz range and the need for capacity per unit area calls for using the higher frequencies and smaller cells. ROF technology can here help reduce antenna complexity by moving signal processing functions away to centralized ends and thus reducing cost and complexity of deployment.

The integration of wireless and optical networks should receive renewed attention by addressing all aspects of related enabling technologies, system design and architectures. The aim should be everywhere provisioning for access and home networks based on optical fibres in the 10 Gbps range with seamless linking of access, backhaul and core network architectures. Modelling and evaluation of such integrated wireless/wireline systems should provide in depth understanding of how network traffic will be supported and evidence of efficiency in handling high mobility and ensuring ubiquitous and seamless services. Integration of optical and wireless networks can foster the emergence of new working practices by increasing remote working and thus reducing the amount of required travel and related carbon emissions. Long reach optical networks can also contribute to substantial energy savings by distributing and deploying

energy consuming processes in the most relevant locations. This vast and multi-facet potential calls for more research in integration of wireless and optical networks.

3.4 Wireless perspective with a cognitive radio and networking view

One of the foundations for Internet (re-)evolution is the drastic growth in terms of number of devices (with different computational capability) levels as well as their dynamic (mainly related to mobility). Hence, it is no feasible to adopt centralized architecture solutions but a rather distributed approach where agents running on top of the devices are responsible for harmonizing the way Internet access devices cooperate to maximize utilisation of communication resources. This harmonization can be achieved first by aggregating information from the different sources, second by inferring both present and near future needs and third by deciding (e.g. using game theory and other relevant approaches) the optimal rule which fits both user and operator interests and expectations. In essence, research and development should aim at harmonizing cognition and cooperation of all involved entities and devices. A fundamental challenge in reaching this goal is the ability to handle very heterogeneous resources. These, including spectrum as the atomic or elementary resource, can even be shared or virtualised, thus adding a degree of complexity in the overall optimization space.

Fulfilling cognition and cooperation in the new Internet implies incorporating self-management functionality in the appropriate entities. These network constituents need to cooperate to acquire a broader and aggregated view of network status to decide on communication resources allocation and management in a more optimal way. Cooperation will not be limited to “peer entities” but span the entire set of layers/strata/abstractions making cross layer collaboration an innate and natural feature in future networks. Challenges such as traffic bifurcation based on data flow content could be more easily implemented while guaranteeing the stability of the network (precious to operators) and meeting QoS objectives (for all involved actors including the end user).

A number of challenges come with the ambition of developing cognitive radio and access systems and networks. The heterogeneity of the technologies and systems is an important aspect, as it requires the ability to discover the surrounding environments and neighbouring systems to build awareness and plug and play into the visited location. The second challenge is the plethora of systems available out there, including alternate emerging ones like visible light communications for short range. At the system and network level, in addition to the cognitive radio level, additional research needs to identify the best ways to use diversity of communications by distributing applications flows into a multi-technology, multi-channels and multi-domain space. The latter involves also end users that can provide additional services that can become as sophisticated as offering connectivity and mobility support services. This broadening of roles and services needs to be taken into account and integrated in future investigations to address competitiveness and relevance of European research and technological development.

3.5 Establishment of Situation Awareness in Network Nodes

Self-management and self-protection requires decision making within the network. The basis for sound decision-making is situation awareness. The more useful information about the current situation and environment is available the more successful can the decision process be fulfilled. Therefore, one key requirement for future Internet architecture is to establish situation awareness in network nodes. It denotes the process of perception of relevant conditions and events. The situational view is the summary of all perceptible conditions and events.

Situation Awareness is established on the one hand by observing and analyzing network node behaviour and information flows in the direct neighbourhood of an entity. On the other hand, cooperation is necessary to provide information on remote events. The situational view provides the basis to decide, based on the current state of the network.

The analysis of information improves the situational view gradually; step by step. If perfect situation awareness is achieved, i.e. all the important factors for the decision are known and processed with respect to the decision-makers' goal, the decision is evident. Nevertheless, this ideal case is usually not achievable due to missing information, resource or time constraints.

Usually it is necessary to make decisions without perfect situation awareness, i.e. with some degree of uncertainty about the situation, in order to invoke actions in time.

Situation Awareness can be subdivided into three levels:

- Perception: Build the situational view by collecting relevant information.
- Inference: Understand the interplay of conditions, as well as other actors' patterns and plans.
- Prediction: Predict future events and actions.

Implementing Situation awareness is not a simple task. Network events are extremely dynamic and difficult to be perceived, interfered or predicted. Hence, the view of the situation needs to be constantly updated. The utopian ideal would be to gain a complete picture of the network, and be able to process it; observe every packet, at every network node, and fully analyze it. Then we could perfectly direct the traffic to avoid congestion and detect even sophisticated application-level attacks. However, since this utopia requires at the very minimum equal processing powers as the rest of the network, we simply cannot measure everything everywhere.

We have in parallel to deal with resource limitations. Processing power, storage, transmission capacity and speed are limited. More dramatically, as network supervision is only a support function for network operation, they should not influence network performance at all. Their costs should not exceed costs for network operation itself. Moreover, the overwhelming amount of result data we could retrieve with specialized measurement hardware has to be processed. Resource limitations are critical in terms of transmission and processing power. They are even worse in wireless networks of small embedded devices and low bandwidth.

In addition it is required to shift from a global network supervision paradigm to an on-demand or pro-active collection of a limited number of relevant local views. As a result it is possible for a given node to change its viewpoint allowing to zoom in or out of a given network region or to follow the trace of an attack to its source. The underlying cooperation for information sharing is essential for Situation Awareness since it provides a way to access information about remote events and is more general the prerequisite for learning from others.

On the other side, privacy concerns have to be respected. Users do not want to reveal too much information concerning them. Providers are reluctant and often prohibited by law to share captured data. User privacy and organizational secrets are at stake. The legal situation is not improved by different legislations across international networks.

4 Recommendations

From the research priorities described in the previous sections, the Expert Group 2 on Post-IP derived a number of recommendations for future networks research and technological development in Europe. The recommendations serve as guideline for National, EU and international funding organisations in specifying their programmes to fund collaborative research projects enabling development of technologies/solutions for future internet.

- Architecture of Future Networks
 - Support bottom-up innovation driven approach towards specification of future architecture(s)
 - IT as well as communication efficient architectural solutions
 - Pursue the design of evolvable networks architectures;
 - Design self organizing mediation and networking architectures;
 - Include and integrate optical networks and high speed wireless;
 - Development of a Network Science to harness complexity and emerging properties;
 - Ensure manageability of future Networks and services through cognition, rules and policies.
- Resources as a Service (RaaS) with auditing and accountability
 - Provide resources as a service with virtualisation as an innate paradigm for a more efficient sharing and use of future networks and energy sources;
 - Ensure auditing and accountability in the architecture;
 - Address resources in the general sense by spanning beyond computer and network resources by including aspects as diverse as spectrum and services;
 - Virtualisation of wireless resources grounded on cognitive radio and networking paradigms are essential;
 - Integrate resources situation and situational awareness as an innate capability and support innate autonomous management and auditing.
- Evaluation methodologies
 - Provide evaluation and validation methodologies and tools to assess architectures, provide proof and validate Future Networks proposals;
 - Use experimental facilities and virtualisation to gradually introduce, deploy and possibly replace legacy systems but also to validate architectures via well defined methodologies.

5 References

[1] See: <http://www.future-internet.eu/home/future-internet-assembly.html> and <http://www.future-internet.eu/activities/fp7-projects.html>

[2] Future Networks, A Portfolio Analysis, DG-INFSO, document can be found at: ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/future-networks/fp7-project-future-networks-portfolio_en.pdf