Autonomicity and Self-manageability Techniques in the Scope of the Future Internet's Evolution

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Abstract. Upon the basis of the essential principles characterizing the development towards the establishment of the Future Internet (FI), the paper discusses innovative aspects for autonomicity and self-manageability, as the latter are introduced by the context of the Self-NET Project effort. We identify the "core" issues for a modern network management activity and related capabilities, incorporated in appropriate network elements/domains (and/or in clusters of them), by considering a novel feedback-control cycle, known as the MDE cognitive cycle. We discuss several major benefits originating from such an innovative approach. Self-NET develops self-management features that alleviate consequences of events for which the system would require various invocations of remedy actions and/or human intervention.

Keywords: Autonomic communications, cognitive networks, Future Internet, generic cognitive cycle model, network management, self-management.

1 Introduction

The Internet has been identified as one of the most critical infrastructures of the 21st century, sustaining social and economic evolution, *just as railways, roads and aeronautic transport networks have been doing over the past century*. It is not simply the "*vehicle*" of a modern services-based economy, *but also a tool to support the appearance of the "fifth freedom" and a truly knowledge-based society* [1]. The transformation the Internet has brought to modern economies and societies will be more apparent in the future, driven by the growth of Information and Communication Technologies (ICT) [2] and by the blossoming of novel business and societal applications [3]. There is a broad consensus that the Internet, *as it is perceived today,* challenges traditional regulatory theories and governance practices. But as the future of the Internet comes

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into consideration, even greater challenges are seen, with many questions related to privacy, security and governance and with a variety of issues related to Internet's effectiveness and inclusive character [4]. Future relevant applications will attract more users to novel services needing greater mobility, wider bandwidth, higher speeds and enhanced interactivity through the launch of many new interactive media and content services [5]. Such demands, *however*, implicate challenges for a more secure, reliable, and scalable Internet architecture. Effectively deployed, the Internet of the future can bring novelty, productivity gains, new markets and growth. In fact, innovative functionalities with more enhanced performance levels are necessary to sustain the real-time requirements of a multitude of novel applications. Furthermore, the Internet underpins the whole global economy. The networking effect has made possible an accelerated and universal diffusion of innovation. The diversity and sheer number of applications and business models supported by the Internet have also largely affected its nature and structure [6]. The Internet is evolving both in its use and in its technology. Born from the vision to create an "open infrastructure" to network computers across the world, the Internet has become a socio-economic backbone of our society, with countless private and business users as well as governments relying on it on a daily basis. The "drivers" for this evolution are a mixture of emerging players with diverse and potentially changing interests, be it users, operators, manufacturers, service and content providers, together with advances in technology that have become available over the years [7].

The ***Future Internet (FI)*** will not be "more of the same", but rather an infrastructure that incorporates new technologies on a large scale that can unleash novel classes of applications and related business models ([8], [9]). If today's Internet is a crucial element of our economy – the Future Internet will play an even more vital role in every conceivable business process. It will become the productivity tool "*par excellence*" [10]. At present, there are many so called "*Future Internet*" initiatives around the world working on defining and implementing a new architecture for the Internet intended to overcome existing limitations mostly in the area of networking [11]. Beyond technological issues, the restructuring of business and social interaction processes unleashed by the Future Internet infrastructure could provide European stakeholders with a golden opportunity to lead a new wave of innovation and to establish a position in the Internet economy that is commensurate with their technological and scientific know-how [12].

Europe remains a global force in advanced information and communication technologies and has massively adopted broadband and Internet services ([13], [14]). The European Union (EU) is actually a potential leader in the Future Internet sector [15]. Leveraging Future Internet technologies through their use in "smart infrastructures" offer the opportunity to boost European competitiveness in nascent technologies and systems, and will make it possible to measure, monitor and process huge volumes of information. This can also provide the means to "overcome" fragmentation and to build a relevant critical mass at European level, while fostering competition, openness and standardisation, involving consumer/citizen, ensuring trust, security and data protection with transparent and democratic governance and control of offered services as guiding principles [16]. The current policy environment for the Internet-based economy is affected by three essential trends, i.e. convergence, creativity and confidence ([17], [18]).

2 Network Management Capabilities in the Future Internet

Innovation, the foundation for economic development, depends on rapid scientific advances. The face of the Internet is continually changing, as new services and novel applications appear and become globally noteworthy at an increasing pace, while new and traditional players are adapting to these challenges through new business models [19]. The current Internet has been founded on a basic architectural premise, that is: *a simple network service can be used as a "universal means" to interconnect intelligent end systems* [20]. The current Internet is centered on the network layer being capable of dynamically selecting a path from the originating source of a packet to its ultimate destination, with no guarantees of packet delivery or traffic characteristics. The end-to-end argument has served to maintain the desire for this simplicity. It is now a common belief that the current Internet is reaching both its architectural capability and its capacity limits (i.e. addressing, reachability, new demands on quality of service (QoS), service/application provisioning, etc). The next generation network architecture will fix the shortcomings of the current Internet, including s*ecurity, privacy, trust and identity management*. It will have "hooks" for business and incentive models, support for semantics, support for mobility, and it will be resilient. This architecture will be flexible enough to support a range of application visions and business models in a dynamic way, ensuring convergence between technology, business and regulatory concerns. New communication technology will enable increasing connectivity, through both wired and wireless communication, both near-range and far-range. Enhanced communication services will open many possibilities for innovative applications that are not even envisioned today. Challenges for the Network of the Future may refer to a great variety of factors, including but not limited to: Dependability and security; transparency (trust); scalability; services (i.e.: cost, service-driven configuration, simplified composition of services over heterogeneous networks, large scale and dynamic multi-service coexistence, exposable service offerings/catalogues); monitoring, reporting and auditability capacities; accounting and billing; Service Level Agreements (SLAs) and protocol support for bandwidth (dynamic resource allocation), latency and QoS; automation (e.g. automated negotiation/instantiation); autonomicity, and; harmonization of interfaces. The resolution of these challenges would bring benefits to infrastructure/network providers, in terms of: Simplified contracting of new business; establishing/identifying reference points for resource allocation and re-allocation; enabling flexibility in the provisioning and utilization of resources; offering the ability to scale horizontally, and; providing a natural complement to the virtualization of resources -by setting up and tearing down composed services, based on negotiated SLAs- thus simplifying accounting and revenue tracking. This can also implicate benefits for service providers/consumers, in terms of: Ready identification and/or selection of offerings; the potential to automate the negotiation of SLA Key Performance Indicators (KPIs) and pricing; reduced cost and time-to-market for composed services; scalability of composed services, and; flexibility and independence from the underlying network details.

A current trend for networks is that they are becoming service-aware. Service awareness itself has many aspects, including the delivery of content and service logic, fulfillment of business and other service characteristics such as QoS and SLAs and the optimization of the network resources during the service delivery. Thus, the design of Networks and Services is moving forward to include higher levels of automation, autonomicity, including self-management. Conversely, services themselves are becoming network-aware. Manageability of the current network typically resides in client stations and servers, which interact with network elements (NEs) via protocols such as SNMP (Simple Network Management Protocol). The limitations of this approach are reduced scaling properties to large networks, and the need for extensive human supervision and intervention. A new network manageability paradigm is thus needed that allows NEs to be autonomously interrelated and controlled, that adapts dynamically to changing environments, and that learns the desired behavior over time. The effective design of monitoring protocols so as to support detection mechanisms critical for the elaboration of self-organizing networks has to be based on a clear understanding of engineering "trade-offs" with respect to local vs. non-local and aggregated information, *for instance*. (Possible techniques for realizing such protocols include distributed tree algorithms, gossip algorithms and stochastic models). Several issues identified in current network infrastructures impose the need for the introduction of an innovative architectural design. More specifically, existing web-based service front-ends are based on monolithic, inflexible, non-context- aware user interfaces (UIs). Furthermore, the diversity of services as well as the underlying hardware and software resources constitute management issues highly challenging, meaning that currently, a diversity in terms of hardware resources leads to a diversity of management tools (distinguished per vendor). In addition, security risks currently present in network environments request for immediate attention. This could be achieved by building trustworthy network environments (as well as communication, computing and storage infrastructures) to assure security levels and manage threats in interoperable frameworks for autonomous monitoring. Another important factor necessitating the need for dynamic FI environments is the reduction of "time to market", referring to the provision of services designated for the end users.

FI's vision, is of a self-managing network whose nodes/devices are designed/ engineered in such a way that all the so-called traditional network management functions, defined by the "*FCAPS*" management framework (Fault, Configuration, Accounting, Performance and Security) [21], as well as the fundamental network functions such as routing, forwarding, monitoring, discovery, fault-detection and fault-removal, are made to automatically feed each other with information (i.e. "knowledge") such as goals and events, in order to effect feedback processes among the diverse functions. These feedback processes enable reactions of various functions in the network and/or individual nodes/devices, in order to achieve and maintain well defined network goals ([22], [23]). Self-management capabilities may relate to a great variety of essential issues, including but mot limited to: (i) Cross-domain management functions, for networks, services, content, together with the design of cooperative systems providing integrated management functionality of system lifecycle, self-functionality, SLA, and QoS; (ii) Embedded management functionality in all FI systems, such as in-infrastructure management, in-network management, in-service management, and in-content management; (iii) Mechanisms for dynamic deployment of new management functionality without interruption of running FI systems; (iv) Mechanisms for dynamic deployment of measuring and monitoring probes for services' and network' behaviors, including traffic. This also implicates SLA-aware sensing and continuous monitoring of systems' adaptations, together with the use of monitoring services in support of the self-management functionality; (v) Mechanisms for conflict and integrity-issues detection and resolution across multiple self-management functions; (vi) Mechanisms, tools and methodology for the verification and assurance of different self-capabilities that are guiding systems and their adaptations correctly; these can also relate to mechanisms for allocation and negotiation of different resources; (vii) Increased level of self-awareness, self-knowledge, self-assessment and self-management capabilities for all Future Internet systems, services, and resources; (viii) Increased level of self-adaptation and self-composition of resources to achieve effective, autonomic and controllable behavior; (ix) Increased level of self-contextualization and context-awareness for network and service systems and resources; (x) Increased level of resource management, including discovery, configuration, deployment, utilization, control and maintenance; (xi) Self-awareness capabilities to support system-level objectives of minimizing system life-cycle costs and energy footprints; (xii) Orchestration and integration of management functions, i.e. a service-driven dynamic orchestration, and; (xiii) Capabilities for the control relationships between self-management and self -governance of the Future Internet.

In such an evolving environment, *it is required the network itself to help detect, diagnose and repair failures, as well as to constantly adapt its configuration and optimize its performance*. Looking at ***Autonomicity and Self-Manageability,*** autonomicity (i.e. control-loops and feed-back mechanisms and processes, as well as the information/knowledge flow used to drive control-loops), becomes an enabler for self-manageability of networks [24]. Suitable equipments and/or systems with communication and computational capabilities can be integrated into the fabric of the Internet, providing an accurate reflection of the real world, delivering fine-grained information and enabling almost real time interaction between the virtual world and real world. In particular, autonomous self-organizing systems are beginning to emerge and to be widely established [25]. Such systems "*can adapt autonomously*" to changing requirements and reduce the reliance on centrally planned services, *especially if they are joined with new network management techniques* [26]. Operators may use these tools to guarantee good QoS service in a period of exploding demand and rising network congestion at peak times. The trend in building dependable real-life systems and smart infrastructures today is "*to move from monolithic, centralized and strictly hierarchical systems to highly distributed networked systems with local and global autonomy*". Some of the challenges for operators and service providers include management (especially in self-organized wireless environments), resilience and robustness, automated re-allocation of resources, abstractions of the operations in the underlying infrastructure, QoS guarantees for bundled services and the optimization of operational expenditures (OPEX). The requirement of a single, scalable and configurable architecture is an essential one of the driving forces for the FI [27]. The variety and heterogeneity of the emerging business models, as well as the dynamic service composition and provision may lead to a situation of many Internets, with different architectural structure, requirements and functionality. Such a scenario will result in a nightmare of maintenance efforts, increased costs, incompatibilities and the like. It is thus important to try to build a single core architecture that maintains properties like configurability, extendibility, scalability and openness. Keeping the core architecture as generic as possible will offer the possibility to easily extend and adapt it to the requirements of the edge. Such a design will follow the rising trend of moving intelligence to the edge of the network.

Nowadays computing systems are open systems evolving in a dynamic complex environment. They are designed as sets of interacting components, highly distributed both conceptually and physically. The growing complexity of these systems and their large scale distribution [28] make the use of traditional approaches based on hierarchical functional decomposition and centralised control no more applicable. Several among the existing technology systems are desired to sufficiently "exhibit" interesting characteristics, such as robustness, capacity of self-management and self-adaptation, as well as survivability in uncertain and dynamic environments. Ubiquitous and self-organizing systems are not only disruptive technologies that impact the way how market actors organize core processes as well as existing structures in value chains and industry, but have also considerable impact [29]. The present Internet model is based on clear separation of concerns between protocol layers, with intelligence moved to the edges, and with the existent protocol pool targeting user and control plane operations with less emphasis on management tasks [30]. The area of FI is considered as a representative example of a "*complex adaptive organization*" (or "*entity*"), where the involved partners have conflicting goals and tension to maximize their gains. Among the core drivers for the Future Internet are increased reliability, enhanced services, more flexibility, and simplified operation. The latter calls for including ***Network Management***[1] ***(NM)*** issues into the design process for FI principles. (In general NM is a service (or application) that employs a diversity of tools, applications, and devices to assist human network managers in monitoring and maintaining networks Thus, network management should be an integral part of the future network infrastructure. Management is a key factor in manageability, usability, performance, etc., and is an important factor to the operational costs of any "network entity". FI requires a new management approach, promoted mainly by the necessity of support interoperability between heterogeneous, complex and distributed systems. In addition, FI should remain open for further and continuous improvement, without the necessity of another disruptive modification in the future. Furthermore, as network management is important for the reliable and safe operation of networks, it is also crucial for the success of the FI. In the scope of these challenges, the ***Self-NET Project*** [31] aims to integrate the self-management and cognition features and the inevitable part of FI evolution [32].

3 The Context of the Self-NET Approach

The novelty factors introduced by cognitive networks appear in a variety of sectors. In particular, the incorporation of a certain degree of intelligence in the network includes an increased capability on a "per element" basis, in terms of monitoring, decision making and execution aspects. Moreover, network nodes themselves can "learn and act" without the need for centralized management mechanisms. Consequently, network environments become more flexible as they are reinforced with self-aware elements, automatic topology discovery mechanisms and several dynamic cross-layer adaptation functionalities. Moreover, dynamic and optimal allocation of resources can

[1] In general, NM is a service (or application) that employs a diversity of tools, applications, and devices to assist human network managers in monitoring and maintaining networks.

be taken into account as a highly significant challenge that could be addressed through novel cognitive networking infrastructures.

The Self-NET Project aims to design, develop and validate an innovative paradigm for cognitive self-managed elements of the Future Internet. The present Internet model is based on clear separation of concerns between protocol layers, with intelligence moved to the edges, and with the existent protocol pool targeting user and control plane operations with less emphasis on management tasks. Self-NET intends to engineer the Future Internet based on cognitive behavior with a high degree of autonomy, by proposing and examining the operation of self-managed Future Internet elements around a novel "feedback-control cycle" (i.e. the "Monitoring/Decision-Making/Execution" or "MDE" cycle) [33]. Thus, dynamic distribution of resources according to network needs at specific time intervals can be pursued by introducing the "MDE" cycle in order to overcome bottlenecks and ensure seamless service provisioning – *even in case of services with high bandwidth requirements*. The completion of the aforementioned objective can make certain better QoS, *beyond the original best-effort status,* and simultaneously eases operational and network management functionalities. Cognitive management in FI elements introduces also innovative techniques regarding converged infrastructures with ultra-high capacity optical transport/access networks and converged service capability across heterogeneous environments.

Self-NET principle design is based on high autonomy of network elements in order to allow distributed management, fast decisions, and continuous local optimization either of existing networks or of specific network parts [34]. The three distinct phases of the Generic Cognitive Cycle Model-GCCM (i.e. the MDE cycle) are the following ones (as illustrated in Fig.1): (i) The ***Monitoring*** *process* which involves gathering of information about the surrounding environment (which can be a complex clustering of several NEs, broader infrastructures and/or related facilities) and the internal state of a Future Internet element; (ii) The ***Decision-Making*** *process* which includes learning, knowledge building and decision-making for reconfiguration and adaptation, by utilizing the developed knowledge model and situation awareness (SA); (iii) The ***Execution*** *process* which involves (self-) reconfiguration, software-component replacement or re-organization and (selected) optimization actions. The Monitoring process receives, *internally or externally*, information about the effectiveness of the Execution process that took place, after the last decision. The Execution and Monitoring interaction is considered as an "*indirect feedback*", useful for system's learning process and, *in sequel*, for the update of the knowledge model. In particular, the Generic Cognitive Cycle model is envisaged to be in the heart of FI Elements [35]. A FI "Element" may be a NE (e.g., router, base station (BS), and mobile device), a network manager, or any software element that lies at the service layer. Future Internet Elements, with cognition embedded [36], will have a process for monitoring and perceiving internal and environmental conditions, and then planning, deciding and adapting (i.e. "self-reconfiguring") on these conditions [12]. Such an "element" is able to "*learn*" (or "*to extract knowledge*") from these adaptations (reconfigurations) and use them for future decision making, while taking into account end-to-end goals, as implied by the considered network infrastructure.

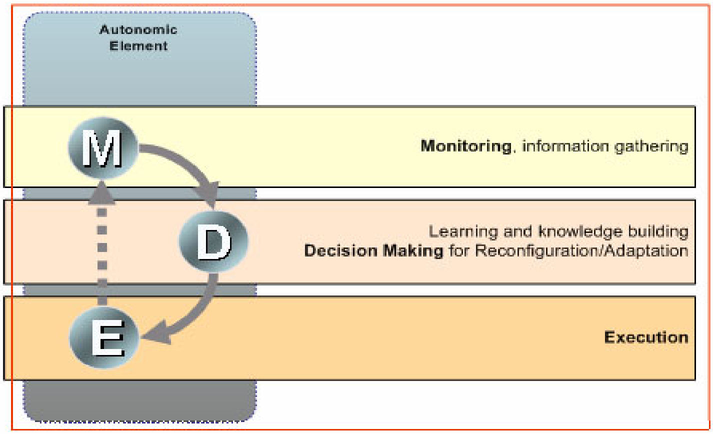

Fig. 1. The Generic Cognitive Cycle Model applied in the Self-NET Context

Cognitive capabilities can enable the perception of the NEs environment and the decision upon the necessary action (e.g. configuration, healing, protection measures, etc.). As current management tasks are becoming overwhelming, Self-NET intends to embed new management capabilities into NEs in order to take advantage of the increasing knowledge that characterizes the daily operation of mobile FI users. Among the main Self-NET's efforts is "*to tackle complexity*" by following the well-known "divide and conquer" approach, that is by: "*Breaking down the overall network management task into smaller manageable tasks and assigning them to individual network elements*"; showing NEs how to tackle the relevant issues; giving NEs the ability to "learn" in order to solve new, emerging (and occasionally "unforeseen") problems; facilitating NEs to cooperatively solve problems that require a sort of coordination, and; enhancing Future Internet with inherent management capabilities *(i.e. "making FI self-manageable").* NEs with cognitive capabilities aim at fast localised decision making and (re-) configuration actions as well as learning capabilities that improve elements behavior. Furthermore, Self-NET intends to provide a peer-to-peer style distribution of responsibilities among self-governed elements of the FI, therefore overcoming the barrier of current client-server and proxy-based models in the operation of mobility management, broadcast/multicast, and QoS mechanisms. A Self-Net's "key-objective" is the provision of a holistic architectural and validation framework that unifies networking operations and service facilities of the FI [37].

FI design is required to provide answers to a number of current Internet's deficits, especially when the danger of increased complexity is more than evident. ***Self-management and autonomic capabilities*** can alleviate this "drawback" by: Providing inherent management capabilities; increasing flexibility, and; allowing an ever-evolving Internet. Towards realizing this aim, the Self-NET Project considers a Distributed Cognitive cycle for System & Network Management (DC-SNM) along with a hierarchical distribution over the network can map self-management capabilities over Future Internet architecture [38]. DC-SNM will further facilitate the promotion of distributed/decentralized management over a hierarchical distribution of management and (re)configuration making levels: (a) to (autonomic) network elements; (b) to network domain types, and; (c) up to the service provider realm, hence allowing high autonomy of network elements with cognitive capabilities aimed at fast localised (re)configuration actions and decision making. Such a distribution brings about the intriguing issue of orchestrating the cognitive cycles (M-D-E) at higher levels of the self-management distribution. The "*decomposition*" of network management into responsibility areas (as shown in Fig.2) can provide the principle on which universal management architecture will be developed, having as a main goal the efficient handling of complexity towards FI environments ([39], [40]).

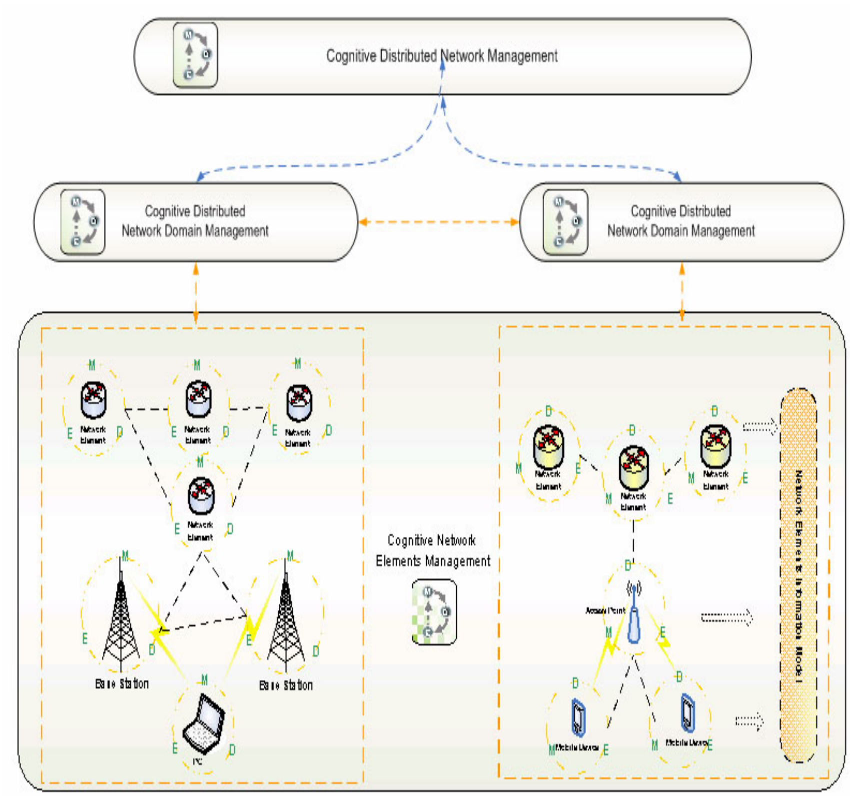

Fig. 2. The proposed Distributed Cognitive Cycle for Systems and Network Management (DC-SNM) purposes

Each element at the identified layers has embedded cognitive cycle functionalities and also the ability to manage itself and make appropriate local decisions. Dynamic network (re-)configuration in many cases is based on cooperative decision of various FI elements and distributed NM service components [41]. Hints and requests/recommendations are exchanged among the corresponding layers, in order to "indicate" (or to identify) a new situation or an action for targeted execution. The automated and dynamic incorporation of various layers requirements (e.g., SLAs (service level agreements)) into the management aspects provides also novel features to NM capabilities. Moreover, the resolution of conflicting requests will be an issue of situation awareness and elements' domain policy prioritization [42]. In the context of the Self-NET Project, the introduction of a hierarchical Cognitive Cycle to enable multi-tier self-management in various network elements and dynamic network compartments provides a quite promising approach to alleviate management overhead, ensure dynamic adaptation to service requirements, situation aware NM and reconfiguration, while coping with the fragmentation of contemporary centralised network management dedicated to specific types of networks [43]. For businesses of all sizes, it is imperative to consider a NM solution that is easy to use, quick to deploy, and offers low total cost of ownership [44]. Such a solution implicates comprehensive capabilities and a satisfactory reliability. The adoption of appropriate cognitive techniques on different platforms (and/or on parts of them, also including connected devices) can be the "kick-off" that will encourage the creation of new networking infrastructures. This implicates several distinct advantages and/or expected benefits, as the latter have been discussed in the scope of previous Self-NET based works [38]. Although there is a diversity of external and influencing available definition on self-management related work ([45], [46]), the term ***"self-management"*** is applied here as the general term describing all autonomic and cognition-based operations in a system. Six relevant distinct methods are identified with specific realizations and purposes; they all serve to demonstrate principles and concepts inherent in the system properties, for achieving completeness and accuracy.

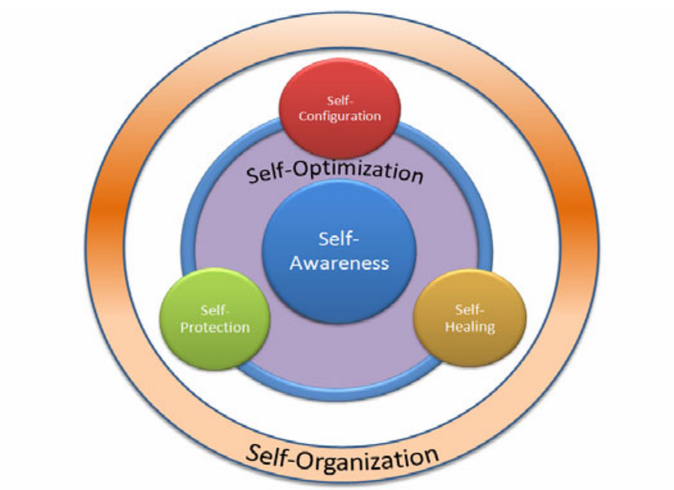

Fig. 3. Definition of the proposed self-management methods

These methods differ in terms of the perspectives on how the systems invoke executions and relevance to the detection processes; they are all depicted in Fig. 3 and defined as follows: (i) ***Self-awareness*** represents the knowledge-building process as a continuous necessity in self-management systems, and it is perceived as "*conclusions derived by the system on being present in a particular operational state (or status) at* *a given time-frame*". (ii) ***Self-optimization*** is system's ability to execute modifications of its operations for attaining the targeted "*optimality point*"[2] in terms of the related performance metrics for a given event. (iii) ***Self-configuration*** is system's ability to accommodate/incorporate new operational aspects in terms of NEs, hardware, software, functional improvements and services that have been provisioned by the operator. The essence of this method is in having the ability to "*add*" and "accommodate" new functional components; (iv) ***Self-healing*** is system's ability to react to unplanned events (such as failures) requiring corrective actions (or countermeasures) and, *accordingly*, to restore or "improve" its operational aspects. The method is rather diverse in terms of the targeted operational aspects that are affected, as this is relevant to the degree of the "healing" required; (v) ***Self-protection*** is system's ability to compensate effects of foreseen events or overcome them completely in terms of their impact on its operational aspects. This is perceived in using the gathered knowledge for deducing the events in advance to their occurrence and then proactively directing specific operations. Emphasis is put on the proactive nature of the system and can also be generalised to identification of external attacks, for which the system's detection process may follow similar pattern(s) of gathering knowledge (but can be overlapping with self-healing in some cases); (vi) ***Self-organisation*** is a specific method indicating ways of collaborations of NEs (or clusters of them) in the context of specific management functions. All the previous self-management definitions specify a broad range of discipline that might be present in self-managed/cognitive systems in FI networks and a diversity of occurrences that can trigger invocations of self-management processes.

4 Benefits Originating from Cognitive Network Management

The adoption of cognitive techniques on different platforms and devices can be the "kick-off" to encourage the creation of new networking infrastructure [47]. For operators and users, the benefits of the introduced Self-NET functionalities in Internet-based architectures can include *inter-alia*:

Automatic planning and reduction of management time of complex network parameters and structures: The current and future anticipated high proliferation of different services that a communications network should support, places a very challenging issue for network operators to solve, and makes the tasks of adjusting network performance and optimizing network resource usage as critically important. Daily (human) network manager activities consist of numerous tedious and time-consuming tasks in order to ensure that the network delivers the desired services to its users. Embedding self-management functionalities in future NEs and introducing cognition in the various network levels (e.g., network elements, network compartments, and network domains) can automate the detection of unusual (or undesirable) behavior, the isolation of their sources, the diagnosis of the corresponding fault(s) and the expected repair of the problem. In some cases, it is also desirable to actually predict

[2] The "optimality point" is considered as a broader term, including a variety of parameters all subject to particular types of events in the system and it is related to the evaluation criteria applied by the involved functionality.

irregular events (like faults or intrusions) and to react, *accordingly*, in due time, as the vulnerability of NEs remains a critical issue for network operators. Applying self-aware techniques in a network environment can thus ease network composition and planning procedures and ensure automatic adaptation of networks and services to the current capabilities of the network components.

Operational costs reduction: Any infrastructure capable of performing automated operational tasks for the aim of optimization of both network efficiency and service quality, can so contribute to the objective of reducing actual network operational expenditures (OPEX). This also enables a more affordable and simpler network deployment. By applying self-management techniques aiming at optimizing the network in terms of coverage, capacity, performance etc., operators can decrease their operational expenditures by reducing the manual effort required to operate a network and can utilize their network elements/resources more efficiently. Furthermore, such techniques can also simplify network maintenance and fault management, by reducing related costs, as well.

Easy adaptation of networks (e.g., in new traffic models and schemes): Traditional traffic management of a communications network usually relies on integrated and centrally coordinated deployment of measures and rules, in response to the current network operating state and/or in anticipation of future needs and traffic conditions. Traffic management configuration of large wireless networks that consist of multiple, distributed NEs of varying technologies is challenging, time-consuming, prone to possible errors and requires highly expensive control & management equipment from any operator. Even when it is initially deployed, it requires continuous upgrades and related modifications so that to provide a uniform and transparent service environment, to sustain high QoS, to recover from faults and to maximize the overall network performance, especially when congestion happens.

Seamless experience to users in selecting a network in a dynamic and robust manner: It is a matter of major importance, for the end-users, to have access to a network providing coverage and services of high quality, on a real-time basis. Self-management techniques imply decentralized monitoring and decision-making procedures so that suitable optimization hints can be extracted in terms of determining the optimum course of actions in order to improve network performance and stability and guarantee service continuity to the users.

Improved service provision and adaptability: Any dynamic detection of operational deficiencies or poor QoS delivered to the end-user, both imply specific remediate actions to be performed, so that to compensate for the related identified problems. Improving the overall network quality also increases subscribers' satisfaction. The optimization of procedures in order to minimize (or even to "*delete*") service failures and to ensure the continuity of service delivery in a network environment, is a matter of major importance for the user and the operator, in a competitive and liberalized telecommunications market.

To enable effective and efficient networking under highly demanding conditions, a continuous NM (proactively and reactively adapted to the network dynamics) is necessary. Instead of using manual techniques, a fully automated, transparent and intelligent traffic management functionality can be much more beneficial. The suggested Self-NET infrastructure can so be used to provide efficient real-time traffic management in a large network, maximizing network performance and dramatically decreasing human intervention. Particular application areas can cover cases of traffic congestion [48], network attachments, link failures, performance degradation, mobility issues, multi-service delivery enhancements and involve intelligent autonomic congestion management and traffic routing, dynamic bandwidth allocation and dynamic spectrum re-allocation [37]. The continuity of service availability influences directly the technical approach of service realization and is an important parameter affecting the planning of the network, so the latter should have the appropriate techniques to "*adapt itself*" to an essential (occasionally prescribed) functional state. The application of self-aware mechanisms can lead to network performance optimization in terms of coverage and capacity, optimization of QoS delivered to the end-user, reduction of human intervention in terms of determining the most appropriate course of actions and proceeding to the implementation of optimization activities. Applying self-aware mechanisms in future networks will contribute towards guaranteeing the following critical features: (i) High availability and seamless continuity of services; (ii) Connectivity anywhere and anytime; (iii) Robustness and stability of the underlying network infrastructure; (iv) Scalability in terms of features and functions; (v) Optimal balance between cost network-related benefits (OPEX reduction – optimized network functionalities), and; (vi) Support for heterogeneity in terms of system components and services.

5 Conclusion

Evolution towards Future Internet imposes the need of building a more flexible and resilient architecture that will serve as the basis for the provision of a diversity of services with optimized quality levels, aiming to the attraction of end users and ensuring at the same time a high degree of satisfaction. Cognitive networks and self-aware functionalities introduce a great degree of autonomy, meaning that embedded and inherent management functionality in several components of FI systems constitute management a "*per NE*" and "*per domain*" mechanism rather than a centralized network functionality. Compared to current networks, self-management techniques pave the way towards automating processes such as the deployment of new NEs, selection and execution of the optimal solution based on specific circumstances and remediation of identified malfunctions with minimum service interruption. New methods (related to embedded and autonomous management, virtualization of systems and network resources, advanced and cognitive networking of information objects), need to shape and re-define the overall FI network architecture. To "encounter" such critical challenges, the main goal of Self-NET Project effort is to specify and evaluate new paradigms for the management of complex and heterogeneous network infrastructures and systems (such as cellular, wireless, fixed and IP networks), taking into consideration the next generation Internet environment and the convergence of Internet and mobile networks. Thus, it can efficiently incorporate new operational capabilities in the "*underlying system*" by introducing novel self-management attributes, resulting in significant benefits. Self-NET develops self-management features that alleviate consequences of events for which the system would require various invocations of remedy actions and/or human intervention. This dynamic behavior and intelligence of handling various events (and/or situations) can potentially lead to an innovative and much promising beneficiary scope of the entire system's operations.

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