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An Approach for Designing Cognitive Self-Managed Future Internet

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Abstract: This paper describes development of cognitive self-managed networks according to the vision of the Future Internet networks being developed in the Self-NET project. The project develops and prototypes architecture and solutions for realising a vision on Internet evolution based on integration of cognition and autonomics in self-managed networks demonstrated in numerous and diverse use-cases developed. The topics presented in this paper show theoretical foundation for building and understanding cognition and self-management and resulting practical realisation and incremental development of them. These include principles of self-managed architecture, path to development of cognition in self-managed networks and logical architecture for inclusion of those concepts. Their resolving and definition demonstrate the practical side of applying diverse available work on the topics and provide a focus for their understanding and development.

Keywords: Future Internet, self-management, cognitive networks, autonomic networking.

1. Introduction

Internet of today has undergone enormous expansions in terms of aspects of its use and operations exemplified in the emergences of vast ranges of services and ever increasing traffic volumes and numbers of users and their characteristics have been followed by the emergence of heterogeneous network environments and technologies applied. This adds numerous requirements and questions on the paths and visions on evolving the current functionality in the Internet or even rethinking the approaches for global connectivity of telecommunication-chain players and users. The complexity of diverse considerations is being instigated by numerous efforts for improving the current Internet where many of these are often combined with the need for convergence with technologies for advancements of mobile systems. Many issues are relevant and drivers of the search for improvement blocks for future Internet networks address complexities, improving or optimising various efficiency criteria, ensuring reliability, robustness and scalability…

The Self-NET project is a European research project [1] part of the Future Internet and Research (FIRE) projects initiative [32], which investigates, designs and prototypes aspects for envisaged Future Internet networks by adding the dimension and potential of applied self-management and use of cognitive functionalities in such networks building on the principles of autonomic network management [2]. Autonomic networking has been a research topics starting with the idea of autonomic control loops in computer systems [5] and various affirming approaches [2][6][7]. The constituent element of the novelty introduced by Self-NET is in realising integrated self-managed, cognitive networks and using this dimension to find novel features and operations of Future Internet networks based on diverse scenarios investigated and tested in the project. The space for advancement of the current Internet features relevant to Self-NET is captured in the high-level definition of the Future Internet vision presented in [3][4] where Self-NET uses objectives of: a) explicit protocol design for a mobile wireless world; b) integrated functional design; c) cross-layer design; d) data/service awareness; and, e) handling service and network complexity. These objectives present a working area where self-management can be applied as a facilitator for orchestrating features of networks. In other words, the possibilities of expanding and enhancing network operations brought about by the potentials of self-management and cognition are developed and used in Self-NET for facilitating novel features in networks. This paper shows main concepts of self-managed cognitive networks that provide guidance for their development. Section 2 presents an overview of the architectural principles followed by definition of knowledge lifecycle. Section 3 presents steps for building the fully fledge cognitive cycle and gives the definition of cognition following it with concepts such as situation awareness.

2. General Principles

Self-NET develops cognitive Future Internet Elements, envisaged as any network elements (e.g. router, gateway, access router…) or higher-level elements such as network manager (residing in network domains) or present in service layers. The cognitive features in any Future Internet Elements are represented by the Generic Cognitive Cycle Model, which contains the Monitoring, Decision-Making and Execution cycle (M-D-E cycle) for conducting the processes of self-management. This breaks down as continuous interactive feedback cycle steps for collection of input on environment and involved elements (Monitoring), reasoning and learning based on the available knowledge (Decision-Making) and invoking actions for solving the desired goals in the system (Executions) [1][8]. Self-NET considers M-D-E cycles in network element level (Network Element Cognitive Managers - NECM), and network domain (Network Domain Cognitive Manager - NDCM) proposing a Distributed Cognitive cycle for System & Network Management (DC-SNM) architecture setup. It aims at decentralisation of decision-making to interactions between NECM and NDCM targeting high autonomy of network elements. The orchestration of the NECMs and NDCMs at the cognitive level as well as the interactions of the cognitive plane with the network element plane and the network management plane is depicted in Figure 1.

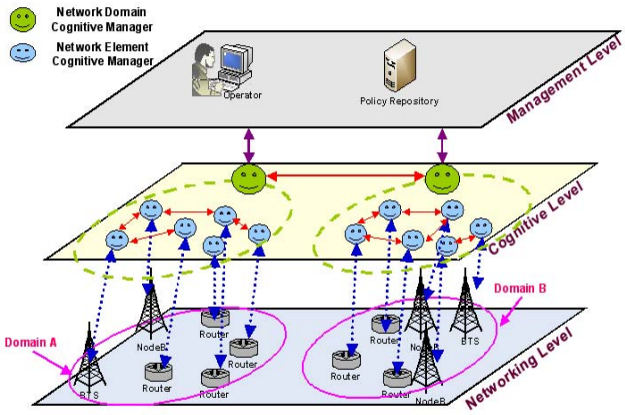

Figure 1. NECMs and NDCMs at the cognitive level in DC-SNM

The term self-management in Self-NET describes all system properties under the umbrella of autonomic and cognition-based operations for performing the relevant operational aspects. There are six distinct methods of self-management defined with specific realisations and purposes in the features of Self-NET systems (demonstrated in Self-NET scenarios and use-cases [8][9]) and they serve to demonstrate the principles and concepts inherent in the system properties. Self-NET compiles and reuses the external definitions and applications [10][11][12][13][14] to the extent possible and defines the six management methods. Four Self-CHOP methods (*self-configuration, self-healing, self-optimisation* and *self-protection*) are reused and two additional methods introduced: *self-awareness* (as the knowledge building process as a continuous necessity and precondition in self-management systems) and *self-organisation* (as an apparatus of collaborations of network elements or clusters in the context of specific management functions). Scenarios and 13 use-cases are derived giving specific technical issues with more precise indications of the elements and processes involved following the objectives of the project in terms of research and experimentations for developing the M-D-E cycle. The use-cases are grouped in six categories:

1. Network Congestion concern management of network resources, especially in terms of bandwidth and service levels. Two use-cases are identified in this category addressing congestions in wireless and wired network.

2. Cognitive Fault Prediction use-case demonstrates that certain pattern can be used to predict occurrences of faults in networks.

3. Intrusion Detection use-case is related to detections of intrusions in systems.

4. Deployment-related use-cases accommodate various types of deployment issues such as additions of network elements with two use-cases dealing with issues of accommodation of new network elements and a specific tools in the network for facilitating the deployment.

5. Use-cases on Failures address system response when identified types of failures occur with two use-cases on detection of various types of failures and specifically, cell outage mitigations.

6. Performance-related use-cases include multitude of various performance improvements in 5 use-cases. The use-cases deal with improving network/cell coverage; adapting congestion control parameters in cell overload conditions; adaptations of handover procedures for performance optimisation; avoidance of spectrum interference; and dynamic protocol stack reconfiguration and incorporation of mechanisms exploiting component-based approaches (e.g. intermediate ARQ).

3. Building the Cognitive Cycle

Based on the scope and diversity of topics contained, in a fully integrated scenario with all use-cases included, Self-NET system would deal with a feedback cycle including multitude of input, complex decision making and learning processes and various possible options for executions and interaction processes at and between NECMs and NDCMs.

3.1 Knowledge lifecycle

From a practical design point of view, levels of cognition are becoming needed and more evident in the system, when integrating increasing number of options and occurrences as described in the use cases. As the integration advances, the system moves from automated responses to cognitive one. Two approaches are applied in developing the cognitive self-management features where this methodology intends to reveal the integration and conceptual aspects. It uses the incremental approach of testing the functionalities (in test-bed scenarios) by developing single use-cases then gradually integrating more of them. In parallel, it develops architectural and conceptual principles of how the fully integrated architecture would operate. The broad scope of areas existent in the use-cases offers the unique perspective of approaching the integration problem from a general point of view showing the conceptual development path. Self-NET defines requirements for characterized and complex structures of information on various predefined and dynamic aspects of system operations. The whole process of information collection and use can be formulated as the knowledge lifecycle. A system theory definition in [15] analysed in Self-NET [30] is used to formulate *categories of interpretation* in Self-NET systems:

- **Data**: collected *raw data* from the monitoring processes. These can be basic numbers, events (interrupts/triggers)…
- **Information**: meaning is given to the data collected. In Self-NET information relates to *operational state of an element of the environment*, e.g. percentage of link utilization or just current throughput for a link…
- **Elementary knowledge**: Refers to the Level 1 of the situation awareness (see next section) process and it is the stage where collected information is *characterized* giving the perception as meaning and relevance to overall system status, e.g. information on the link utilization can lead to elementary knowledge interpretation that link is congested (or in risk of), characterization being predetermined by system designer.
- **Cognition (understanding)**: refers to interpreting the whole impact and implications of the elementary knowledge as the triggering process for conducting the system response via situation awareness steps (and decision enforcement). For this purpose, many knowledge sources, i.e. knowledge base, and learning processes need to be invoked and system dynamically updated with new operational states, i.e. self-awareness.

Knowledge refers to and is applicable to different structures of information and various stages of cognitive processes following similar approaches [16][17][18][19]. It also has the property of being predetermined and used for interpretation purposes but also dynamic and used for generating the updated statuses of the system (e.g. in self-awareness). Knowledge definition is not a one-dimensional process as the terms can be used for a) interpretations, b) instructions and c) dynamic assessment of system states.

3.2 Path to Cognition

If a stand alone network element is observed, a simple **automated** response can be associated to a single trigger event and designed response. The cognitive cycle then takes a simplest possible form of M-D-E realisations with no complexity and cognition applied in any of the processes associated nor application and use of the *categorise of interpretation* of data, i.e. no *knowledge lifecycle* being present in system operations. Monitoring in such an automated case is simply expecting particular types of data with straightforward inference of information leading to *"if-then"* type of decision making and invocation of a preset execution as depicted in Figure 2. with simple loopback process with minimum feedback actions in terms of state updates and no invocation of knowledge processes. *Self-awareness* can be assumed minimal and existent only to the extent of the available internal data present by default in the element possibly used for affirming the certainly of the *"if-then"* decision making. This type of response can also be referred to as a *reflex* action due to its lack of processing of input, any complex inferences or deduction processes and no reasoning in the decision making. In simple terms, there is only one disposable option available for execution processes.

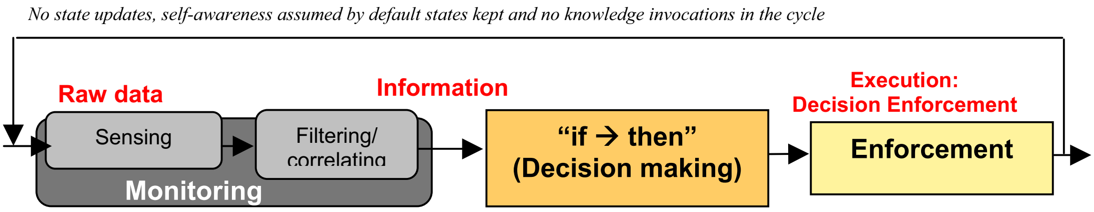

Figure 2. A simplified representation of the M-D-E cycle in the basic automated *"reflex"* case

The basic automated example can serve as the starting point in the explanation of the path to cognition represented by fully fledged cognitive cycle. M-D-E cycles can be further expanded with more elements of the cognitive cycle adding complexities in interpretation of input via Monitoring, more parameters and choices in the Decision-Making and Executions. From the practical point of view and its representation in the cognitive cycle, self-awareness is seen as the elements' view on the internal and external processes, statuses and states needed for conducting the deduction processes in the cognitive cycle. As the focus is on devising the network elements' cognitive cycle, in the first iteration of development, internal view is seen as all the needed information kept in the element(s) while the external view is the information collected from the domain element or neighbouring elements via the domain element or directly (these actions are assumed performed by NECM and NDCM respectively). This information is additional to the ones that would be available by default and required for cognitive cycle processes. Hence, this assumes that the design and purpose of the cognitive cycle dictate that there is an inevitable necessity for collecting and maintaining such extra information.

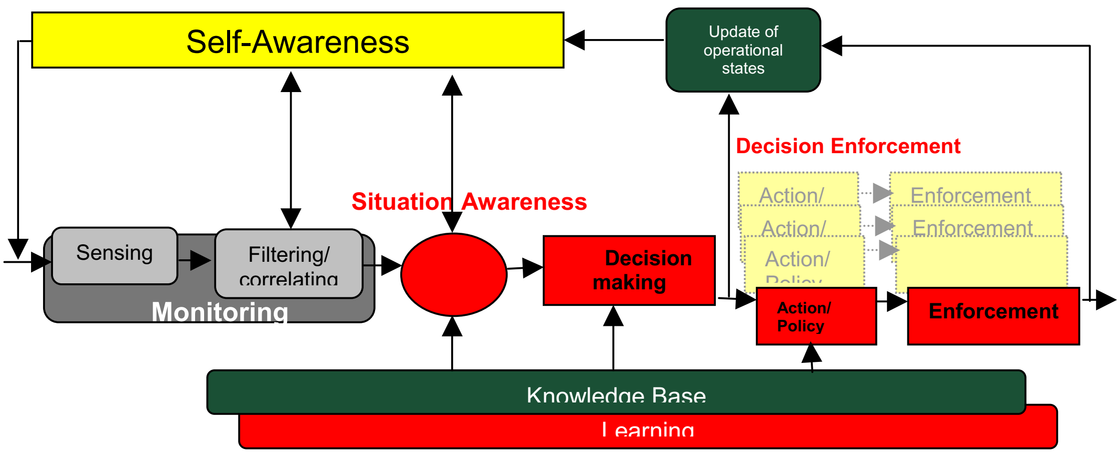

Figure 3. Self-NET logical architecture of the cognitive cycle for self-management

A representation of the logical Self-NET architecture for cognitive self-management is shown in Figure 3. presenting the cognitive cycle (note many intermediate cognition example are possible with reduced level of functionality). The main conceptual foundation for introducing the figure as the final view on realisation of cognition in self-management systems is the Self-NET definition of cognition: *Cognition in self-managed systems is defined as the ability of the systems' self-managing elements to handle multitude of input parameters and system statuses, deduce diverse ranges of situations in systems and* *accordingly perform decision making with considerations for the implications of choices in invocations of available executions options. A cognitive system deals with multidimensional implications of monitored data and multiple choices in deciding executions.* This is an idealistic view in a fully integrated system in a scenario of a fully realised DC-SNM architecture and completely developed network and domain elements being able to cope with all ranges of situations defined in Self-NET scenarios and use-cases. The previous example and other representations that can be defined with various levels of cognition (cognition levels assumed as diversity of choices in deduction and decision making processes) are demonstrating the introduction of concepts but also a path to realisation of cognition in systems. Such a path provides a development roadmap, particularly important in Self-NET due to its inclination to experimental as well as theoretical research and development. Self-NET applies the incremental approach of testing the functionalities by developing single use-cases and system capabilities then gradually integrating more of them. In parallel, it develops architectural and conceptual principles of how the fully integrated architecture would operate. However, even in the fully realised case, processes of the cognitive cycle sufficient for a given purpose can be subject to arbitrary levels of invoked processes with choices dictated by the design guidelines set be the system administrators. Situation awareness is added in the cognitive cycle in Figure 3. following its definition in Self-NET [29][30][31] as an instrument for processing monitored input taken from similar purposes in dynamic systems [20][21][22][23][24] and adopted in autonomic networking scenarios [25][26][27][28]. Self-NET has proposed a specific model for its integration primarily aiming at having an instrument in cognitive systems *"to handle multitude of input parameters and system statuses, deduce diverse ranges of situations in systems"* following the above definition of cognition. Ranges of execution options are presented in Figure 3. to indicate the possibility of invoking several execution choices by the decision making, e.g. various congestions and failures can be solved by various execution options for redirecting the traffic, reducing the traffic rate…Knowledge base shown in Figure 3. contains the interpretations and instructions for processes being discovered and requiring actions in the cognitive loop and via design and learning can be expanded for accommodating more choices and increments in the levels of cognition.

3.3 Summary of Situation Awareness

Situation awareness in Self-NET is the ability to known and deduce what is happening in the network, involving the comprehensive set of data inputs and related to the environment in consideration. For understanding these processes, Figure 4. shows basic instances and processes of the cognitive cycle parts indicating the stages corresponding to situation awareness. Situation awareness is the step that precedes and constitutes the foundation for decision-making. Its ultimate result is a validated *situation* being the point at which an instance of situation awareness process is completed hence progressing to the decision-making part. Thus, decision making has the full awareness of the system statuses represented in the *situation* resembling a view or comprehension that a network administrator would have when a certain event (trigger)/information/data is obtained and analysed from the current operational aspects in the system. This assessment is not related to processing of single information and state but to comprehensive assessment relevant to many aspects and conditions of the overall situation that is analysed following the definition of cognition. A situation is not a single statement on the condition or information about an aspect of the system (e.g. link congested or link failed) but a completed assessment of the environment related to the invoking data/information collected and resolved with and between the elements and domain level of the cognitive managers.

Self-NET has situation awareness in the following manner along with the use of the knowledge base:

Level 1 of Situation Awareness: Characterisation of Operational States/Perception: *information* becomes *elementary knowledge* as described above in knowledge lifecycle categories of interpretation. A description/characterization of operational state(s) is created, where operational state refers to operation of a segment of the system, physical and/or logical. E.g. information 90% link/buffer utilised can lead to characterisation that link is being congested above the tolerable threshold predetermined systen designers, i.e. this would be included in situation trigger progressing to Level 2 Situation Awareness, otherwise the system loops back to monitoring.

Knowledge Base - Interpretation Library of Operational States: refers to the database where characterizations are stored/predetermined (self-awareness plane might be consulted as well). E.g. thresholds/ hysteresis/ complex information relations… Situation Trigger is an abstraction to indicate progression to Level 2 Situation Awareness, i.e. environment needs to be assessed (arrows show progression to Level 2).

Level 2 of Situation Awareness: Assessment of the Environment: this is analogous to network administrator response to an event/information. When there is a situation trigger the environment needs to be assessed in order to prepare for decision-making, e.g. checking alternative links available to relieve congestion. Self-awareness provides information on the environment related to the assessment.

Knowledge Base – Procedures for Assessment of the Environment: refers to databases of procedures for assessment of the environment, i.e. analogous to network administrator training. Deduction Completion is an abstraction to indicate finalisation point of all checks for assessment of the environment. These are conditions for moving to the decision making stage (indicted with arrows) e.g. alternative links found and operational…In case of predictions (i.e. needed Level 3 Situation Awareness) this additionally refers to what needs to further happen to deduce a situation and proceed to the decision making stage.

Level 3 of Situation Awareness: Projections: Prediction on what would happen in the future based on the current assessment of the environment and/or what conditions should be met to proceed to decision-making.

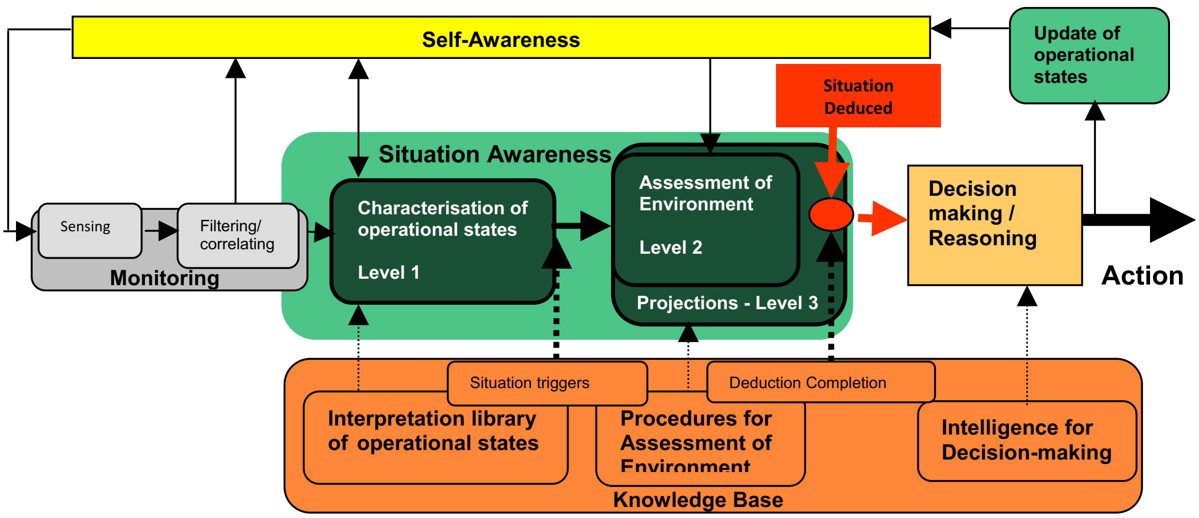

Figure 4. Situation awareness in Self-NET cognitive cycle

4. Conclusions

This paper demonstrates development of concepts that constitute one of the main issues in the design of self-managed cognitive networks for Future Internet vision as currently developed in the Self-NET project. This is necessitated by the specific scope of Self-NET starting with objective of developing functionalities for self-management and cognition and their prototyping by using an approach where the whole problem is observed from a broad scope point of view in order to understand and enable the transition from automated to cognitive behaviours. This is captured in the extent of areas considered in the use-cases and application of architectural principles for integrating and understanding how they would coexist in future networks. Based on the available outside work on topics related to this objective this paper unifies and formulates some of the main issues required for development of cognitive self-managed systems and is currently performing implementation of these is real test-beds which will reveal the practical realisation and coordination issues in deploying the cognitive cycles in use-cases and applying the theoretical background presented in this paper.

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