Functional blocks and Enablers for the Coordinated Control of autonomous and distributed Future Networked Systems

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***Abstract*— Future Internet (FI) constitutes a highly decentralized and dynamic environment of resources and systems whose complexity imperils the network stability, jeopardizing the network performance and compromising an optimized use of resources. In this context, the UniverSelf research project proposes a promising solution, called Unified Management Framework (UMF). UMF targets include the trustworthy network stability, which is accomplished through the coordinated control of the autonomous and distributed future networked systems, based on operator's objectives. Accordingly, this paper presents the relevant UMF operation, including a description of its functional blocks and their underlying mechanisms. In the framework of this solution, the paper also describes the Network Empowerment Mechanisms (NEM) that empower networks with autonomic algorithms/solutions and can be embedded into existing and future systems in a "plug and play" way.**

***Index Terms*— Autonomics, Unified Management Framework (UMF), Coordination, Network Empower Mechanisms (NEMs), network stability.**

I. Introduction

FUTURE Internet (FI) [1] will be characterized by powerful infrastructures, comprising an exponentially increased number of autonomous and distributed network systems, and services, comprising advanced applications for all areas of human activities and content provision; operating in the context of existing, evolving and emerging business models (e.g. consortiums of network operators, virtual network operators, service and content providers, and trusted independent third parties for security and certification, with new cooperation capabilities, roles and functionalities).

Autonomous systems, which are characterized by self-management (encompassing self-configuration, self-healing, self-optimization, and self-protection [2]) and cognition, enhanced by learning capabilities and knowledge management, comprise one or more self-adjusting closed control loops, in order to achieve their operating goals in the framework of the operator's and user's demands. Obviously, as the number of the distributed systems that control or influence the behavior of the overall network increases, it has become more difficult to understand and predict how these systems will interact. Consequently, this highly decentralized and dynamic environment of resources and systems is a serious threat for the network stability (i.e. approved network performance, almost steady, irrespective from the different processes that are executed in parallel). Network instability may have primary effects, both jeopardizing the network performance and compromising an optimized use of resources. An emerging and extremely challenging solution to this problem is the coordinated control of the networked systems. The coordination function should cover the identified gaps/requirements of FI regarding distributed coordinated solutions to networking problems, assurance of interoperation, cooperation and federation of multiple autonomous systems, and detection and resolution of conflicts among actions of autonomous networked systems, which will enable delegation of autonomous decision making.

The coordination decisions should be taken in the framework of policies, which reflect the operator's strategy and are altered based on network status, the operator's goals and the needs that accrue from the cooperation agreements with other operators/providers. Obviously, the aforementioned function needs accurate and always up-to-date information provision, and subsequently, information collection and processing, and production of relevant knowledge.

To this effect, the UniverSelf project [3] funded by the 7th EU Framework Programme, proposes the so called Unified Management Framework (UMF). UMF is an innovative management framework that aims to solve actual network problems and to address the aforementioned requirements. UMF introduces the concept of Network Empowerment

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Mechanisms (NEMs), which encapsulate autonomic functions (closed control loops/algorithms) that can be embedded into legacy and future systems in a "plug and play" way. NEMs are designed targeting at specific network segments/elements or service infrastructure, and are deployed with a specific purpose: an operational problem/condition to be solved/optimized. Therefore, NEMs can be developed by any actor of Information and Communication Technologies (ICT) market: equipment manufacturer, network management system vendor, network operator, etc.

In this context, the primal objective of the UMF is to enable trustworthy integration and interworking of NEMs within the operator's management ecosystem. The achievement of this objective necessitates NEM's orchestration/coordination, NEM's governance/administration, as well as sharing of information/knowledge among NEMs. This demand leads to introduction of the concept of UMF core, which consists of three enabling components, Governance (GOV), Knowledge (KNOW) and Coordination (COORD), enhanced by proper mechanisms that enable the realization of their functionalities.

This paper firstly presents concisely the UMF core concept in Section II, and then, the Coordination core component along with the functional blocks and the mechanisms that enable its realization, in Sections III, and IV, respectively. The paper is finally concluded in Section V, providing also next steps of the work.

II. UMF CORE IDENTIFICATION

The design of UMF [4], based on requirements of FI networks, led to the UMF specification, which consists of a set of functions that resolve manifold networking problems. UMF Core consists of three components, Coordination (COORD), Governance (GOV) and Knowledge (KNOW), and incorporates a set of key functions of UMF. The UMF core components are concisely presented in the sequel and are depicted in Fig. 1.

The Governance core component is responsible for the interaction between human operator and network, and the determination of the behavior of the autonomous and distributed networked systems. The former is accomplished through a privileged, powerful and evolved human to network interface, which will be used by the human operators for expressing their business goals and requests, shifting from network management to network governance [5]. The latter is accomplished through a policy-based framework that enables translation of the business-level, service specific goals/requests (highest level policies) into low level, semantically rich policies and configuration commands [6]. These policies and commands are enforced through the individual systems, the interoperability of which should be supported.

Coordination core component, the operation, the functional blocks and the enabling mechanisms of which are presented in the sequel, is responsible for the cooperation/orchestration of NEMs, in order to achieve specific operations, solutions of definite problems, and stability of the whole network [7].

Knowledge core component provides all the necessary functionalities related to information collection for both network and services, information processing and knowledge derivation, as well as, aggregation, storage and distribution of this information/knowledge to the NEMs.

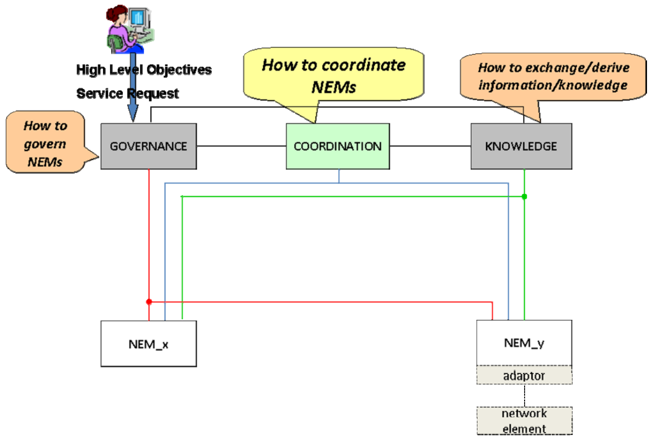

Fig. 1. UMF core

III. COORDINATION FUNCTIONAL SPECIFICATION

Each NEM, after its installation to a network element, is registered to COORD. The NEM registration comprises the scope of NEM's operation, NEM's output, NEM's configuration parameters (including requirements regarding information/knowledge input), capabilities regarding information/knowledge sharing, metrics, timing demands/preferences (e.g. typical period of the NEM), and utility functions with probable weighting factors. Based on this information, after each new NEM registration, COORD investigates the new capabilities of the system/network, and the probable conflict of the operation/outcome of the new deployed NEM with the currently managed NEMs/elements. After the completion of the inquiry, COORD updates its coordination/conflict map, adding the examination results. The coordination/conflict map includes the resolution schemes, namely the NEMs that can cooperate for the encounter of a defined network situation/problem and the corresponding default triggering sequence for them, as well as, the potential conflict between the managed NEMs, the possible influence to network stability and performance, and the chosen coordination strategy for the conflict avoidance. Moreover, after the registration of the NEMs, based on the corresponding information, the functions are associated with the NEMs that are going to be controlled by them.

COORD communicates with KNOW in order to obtain the necessary relevant information on the specific scenario/problem, that is needed for its operation and is not included in the NEM registration information. The requested information includes network status information and NEM related information (e.g. mean time duration of NEM algorithm execution for each of the NEMs that are involved in the designated operation). The NEM related information can also be asked directly from the NEMs, which is what is happening if the returned information from KNOW is not sufficient. The requested knowledge corresponds to probabilities of specific operation/behavior of the involved NEMs in the particular scenario [8].

COORD intervenes with the NEM's operation when the NEM's action has to be synchronized with the actions of other NEMs, in order to achieve a specific network target, or when its outcome may influence the operation of the whole managed system/network causing network instability or performance degradation. In these cases, COORD determines the time instance that the NEM is allowed to perform its action and grants a token (corresponding to specific time interval) to the NEM, which gives it the permission to execute its optimization (closed control loop/algorithm) action and enforce the resultant output. Furthermore, COORD may guide the NEM's behavior with control policies, which set values to NEM's configuration parameters or impose constraints to the optimization operation.

NEM has the knowledge of its role to an integrated operation, and the awareness and cognition to detect the network's or system's conditions that needs its activation. In this case, the NEM requests a token, in order to execute its action, which is returned to COORD after the completion of its operation. Moreover, NEMs, based on their information/context exchange with KNOW and their awareness capability, are able to collaborate and exploit the information/knowledge of other elements, without the interference/control of COORD, in order to improve their performance.

In this framework, COORD consists of four functions, which are depicted in Figure 2, Orchestration, Conflict Avoidance, Joint Optimization, and Stability Control.

The Orchestration function is responsible for the orchestration of NEMs, in order to achieve, through their cooperation, specific operations and solutions of definite problems. Specifically, it:

- Determines the triggering sequence for coordinating NEMs, and controls the right triggering order.
- Sets the appropriate constraints for a NEM's function and updates the suitable parameters of NEMs' configuration, in order to satisfy the corresponding GOV policies.
- Guides the outcome of the other COORD functions, through proper policies/directives, in order to ensure compliance with the overall orchestration constraints, and consolidates their decisions, in case there are different or even contradicting decisions for the encounter of a specific situation.

Conflict Avoidance function is responsible for the detection and avoidance of conflicts between NEMs, and Joint Optimization function is responsible for optimization of the whole managed system through tuning of active tightly coupled NEMs. Finally, Stability Control function provides special stability control functionalities, which encounter the instability features that may arise despite the existence of the other functions. Stability Control function guarantees network stability, and, consequently, enhances the trust to autonomous and distributed networked systems.

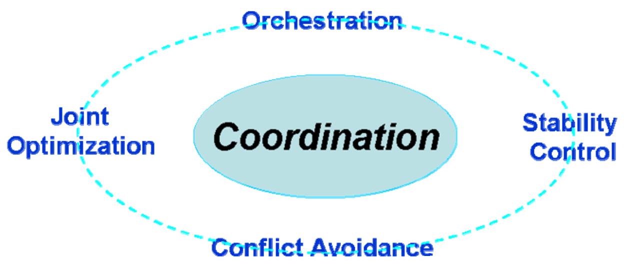

Fig. 2. Coordination functions

It is noted that all the COORD functions are learning-capable, which enables the understanding and controlling/managing of the network behavior, through the proper coordination of the distributed networked elements, in order to meet the demanded technical and business objectives. Specifically, regarding Stability Control, the learning capability enables the definition and assessment of stability models for available network features and to predict the stability levels of the network after a knowledge based configuration.

IV. COORDINATION ENABLERS

The operation of the coordination functions needs the necessary mechanisms, which will enable the achievement of their objectives. Orchestration function, regarding the construction of the initial triggering sequence and the appropriate constraints that should form the framework of NEM's operation, is realized based on relevant GOV policies and current scenario requirements. A number of mechanisms can be considered in the context of this function, with various levels of complexity and intelligence, which is instructed by both the nature of the NEMs that are to be coordinated and also their capabilities in terms of providing the required inputs to the coordination mechanisms.

One key factor that influences the selection and applicability of the appropriate coordination mechanism is the timing of NEMs, leading to a category of mechanisms that are based on the "separation in time" strategy. The separation in time strategy in principle dictates that conflicting NEMs should not be allowed to execute simultaneously their enforcements to the network. For NEMs that have similar time scales this translates into mutual exclusion strategies, where only one NEM at a time is allowed to execute and enforce its actions. In the simplest form, this can be implemented by a random token passing mechanism, where the selection of the NEM to "run" is very simplistic, without taking into account network performance objectives. This method, however, even though simplistic, it offers the advantage that poses very minimal requirements into NEMs in terms of having to be able to predict the outcome of their actions.

A more sophisticated application of a separation in time strategy is through the incorporation of utilities and performance objectives in the token assignment decision. This means that all NEMs that are due to “run” at a certain time point are able to predict the outcome of their actions (if they were to “run”) and the token can be assigned not randomly, but each time to the NEM whose action is expected to maximize the network utility at that time point. In this case, the corresponding mechanism targets at achieving conflict avoidance and optimization of network utility, coinstantaneously.

Contrary to “separation in time” strategies, an alternative approach to the coordination problem is to try and find a compromise in NEMs actions that maximizes an objective function indicative of the network performance. That is, NEMs are not mutually excluded from running but they are considered at the same time. However, their actions are coordinated so that they are not selfish and possibly even contradicting but they complement each other in the best possible way. A straightforward solution for this would be to integrate their objectives into one optimization function. In this way, the common function will handle the conflicts of the two or more, maybe competing, objectives. A well elaborated approach to do this is through multi-objective (MO) optimization. There are several methods to solve a multi-objective problem. Some classical methods consist of converting the MO problem into a single objective (SO) problem by either aggregating the objective functions or optimizing one objective and treating the other as constraints.

Joint Optimization mechanism is based on construction of a global system’s utility function, deriving from policies (corresponding to specific weights for defined utilities) and NEMs’ parameters, metrics, and utility functions.

Stability Control mechanisms perform off-line tests to validate levels of indicators of network stability and performance, detect real-time network instabilities and performance degradation by monitoring specific operations, and resolve these problems by triggering enforcement of configurations (specific NEM’s actions) for stabilization, or de-activating the NEMs, which have been detected as problem cause. In this context, two types of objective functions are utilized with alternative ways: a sum of utility functions by end users, such as rate, reliability, delay, jitter, power level, and a network-wide cost function by network operators, such as congestion level, energy efficiency, network lifetime, collective estimation error.

V. Conclusion

UMF is an operator-driven, unified framework for establishing autonomic network and service management, which constitute a solution for coordinated control of the autonomous and distributed future networked systems. The specification of UMF core and the respective coordination operation were concisely presented and resulted from identified requirements of FI networks.

Next steps include the detailed specification of the mechanisms that enable the relevant functions, and the interfaces between the core components and the distributed future networked systems. Moreover, validation of UMF will be performed through prototype implementations, in order to be guaranteed the trustworthy coordination of the distributed systems, which leads to proven network stability and is required as step towards the adoption by the ICT industry and the network operators.

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References

[1] European Commission, Information Society and Media, Future Internet 2020, Visions of an Industry Expert Group, May 2009.

[2] N. Samaan and A. Karmouch, “Towards Autonomic Network Management: An Analysis of Current and Future Research Directions”, IEEE Communications Surveys & Tutorials, vol. 11, no. 3, 2009, 3rd Quarter 2009, pp. 22–36.

[3] UniverSelf Project, http://www.univerself-project.eu

[4] K.Tsagkaris, A.Galani, P.Demestichas, G.Nguengang, M.Bouet, I.G.Ben, C.Destre, S.Ghamri-Doudane, L.Ciavaglia, “Designing the core components of an operator-driven, framework for unifying autonomic network and service management”, Future Network and Mobile Summit 2012, 4 - 6 July 2012, Berlin, Germany

[5] A. Galani, K. Tsagkaris, P. Demestichas, G. Nguengang, I. GridaBenYahia, M. Stamatelatos, E. Kosmatos, A. Kaloxylos, L. Ciavaglia, “Core functional and network empower mechanisms of an operator-driven, framework for unifying autonomic network and service management”, Special Session on Modelling Tools, Network Empowerment Mechanisms & Testbeds for Future Service-&Operator-oriented Internet, 17th International Workshop on Computer-Aided Modeling Analysis and Design of Communication Links and Networks (CAMAD), September 2012, Barcelona, Spain

[6] A. Galani, N.Koutsouris, K. Tsagkaris, P. Demestichas, B. Fuentes, C. Garcia Vazquez, G. Nguengang, “A Policy based Framework for governing Future Networks”, accepted at the 4th IEEE International Workshop on Management of Emerging Networks and Services (MENS 2012) at the IEEE Global Communications Conference (GLOBECOM 2012), December 2012, Anaheim, California, USA

[7] UniverSelf Project, Deliverable D2.1 UMF Specifications Release 1, July 2011

[8] K.Tsagkaris, A.Galani, P.Demestichas, G.Nguengang, M.Bouet, I.GridaBenYahia, C.Destre, S.Ghamri-Doudane, L.Ciavaglia, “Identifying standardization opportunities of an operator-driven, framework for unifying autonomic network and service management”, Workshop on Telecommunications: From Research to Standards, IEEE ICC 2012, June 2012, Ottawa, Canada