Proof of Concept

Governance Framework for Network Optimisation

Abstract

This document describes UniverSelf Prototype 2 entitled 'Governance Framework for Network Optimisation', in terms of its context and implementation aspects, key results and findings. UniverSelf Prototype 2 is a subset of use case 7 entitled Network and Service Governance. This prototype aims to demonstrate a policy-based governance approach to manage different types of network mechanisms, within the wireless testbed and a simulated LTE Radio Access Network. The results validated the deployed mechanisms, in terms of performance and efficiency gains and automation.

Date of release

17/10/2012

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ABOUT UNIVERSELF

Four challenging objectives

UniverSelf is an FP7 IP project that addresses autonomic networks and the interoperability of their parts in a holistic manner, i.e. including both wireline and wireless parts of the network. This project is vital because the operational complexity in an operator's network is growing, because the cost structure of the current management model is not sustainable, and because the already existing management architecture is no longer adapted. Correspondingly, the four main objectives of UniverSelf are:

- Design a Unified Management Framework for the different existing and emerging architectures, that is cross-technology (i.e. wireless and wireline) and will serve as a common platform for both systems and services.
- Design the functions that will enable self-managing networks and embed these functions directly within the systems and elements that comprise the network infrastructure and support service delivery.
- Demonstrating the potential for deployment of autonomic solutions in carrier grade networks with an eye towards stimulating further research in Europe towards application and commercialization.
- Generate confidence in the viability and use of autonomic technologies in telecommunication networks by defining "certification" parameters for autonomic networking products.

These core objectives will be evaluated against three main, tangible targets.

- Target n°1: Reduction of the Operational Expense (OpEx)

  The target is to reduce by 30% the OpEx associated to the scenarios and use-cases which will be covered and studied during the life time of the UniverSelf project.
- Target n°2: Standardization of the Unified Management Framework (UMF)

  The target is to achieve the specifications of UMF components in Standard Development Organizations (SDO) to guarantee reference and interoperable autonomic systems.
- Target n°3: Industrial adoption ratio

  The target is to measure, based on a set of different quantifiable criteria, how much UniverSelf helped or contributed to the adoption of autonomic networking paradigms by the industry. The objective is also to quantify the project achievements to bring the autonomic networking topic from a research thematic to an industrial issue.

A pragmatic methodology

UniverSelf approaches the holistic network and service management challenges with three technical work packages:

- Unified Management Framework (WP2) that addresses the question how multiple management functionalities can successfully work together. The ultimate goal is a specification that provides a standard for the interfaces between a management functionality with the overall framework.
- Network Empowerment (WP3) with the goal to find appropriate algorithms and methods for the management problems.
- Deployment and Impact (WP4) that provides and assesses problems in a use-case style and approaches both the business impact and the question of trust and a corresponding certification process.

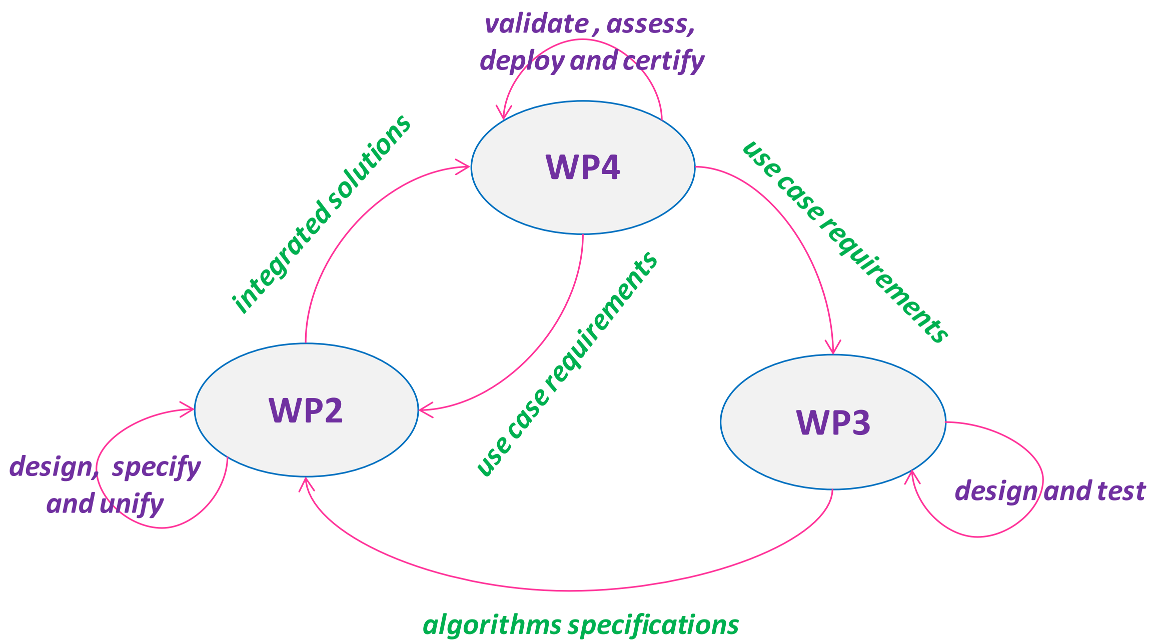


Figure 1 : High level view of UniverSelf methodology

Industry-focused and representative use cases

The following use cases are addressed in UniverSelf:

- Self-diagnosis and self-healing for IMS VoIP and VPN services
- Network stability and performance
- Dynamic virtualization and migration of contents and servers
- SON and SON collaboration according to operator policies
- Operator-governed end-to-end autonomic joint network and service management
- Network and services governance

In this document we focus on the fifth use case, i.e. “operator-governed end-to-end autonomic joint network and service management”. This use case in principle bears several problems, namely the enablement of operators to describe their goals and objectives in high-level terms (human to network interface), the analysis of business requests, the determination of candidate solutions, the invocation of the selected radio access networks and the request for an offer in terms of the quality which said network can provide, likewise the invocation of backhaul/core segments, and finally the resolution of possible incompatibilities between the offered QoS of radio access networks and backhaul/core segments, respectively. In this document we will focus on UC 7 Network and services governance.

An impactful experimentation strategy

UniverSelf aims at demonstrating the feasibility and efficiency of the project solutions, mechanisms and algorithms in a proof-of-concept environment comprising simulation modules and prototyping activities, together with testing and assessment capabilities. The experiments will be driven, prioritized and refined by the project use cases and scenarios. UniverSelf will approach the refinement, assessment and validation of theoretical work through a framework for proof of concept, validation, simulation, experimentation and demonstration. This is our experimentation strategy and the corresponding timeline is highlighted in **Figure 2**.

The validation part of this activity will also address feasibility aspects, as well as assessment of key performance or stability, scalability etc. indicators and will work especially on the integration of the solutions in and via the Unified Management Framework (UMF).

Experimentation can be seen as a concrete methodology for the production of validation results close to real life scenarios. Experimentation and validation activities will focus on the collection and analysis of metrics related to the achieved performance and optimization benefits, QoS in service provisioning, the end-to-end coherence of management actions, the system's stability and responsiveness, the realized compliance to the imposed policies and profiles, the CAPEX and OPEX gains etc… The main capabilities targeted for the federated framework for the experimental facilities, will be the computation resources, the incorporation of heterogeneous wired and wireless systems and network management operations (emphasis on the autonomic aspects). Moreover, issues related to the business sustainability and user acceptance and trust in autonomic solutions can be addressed.

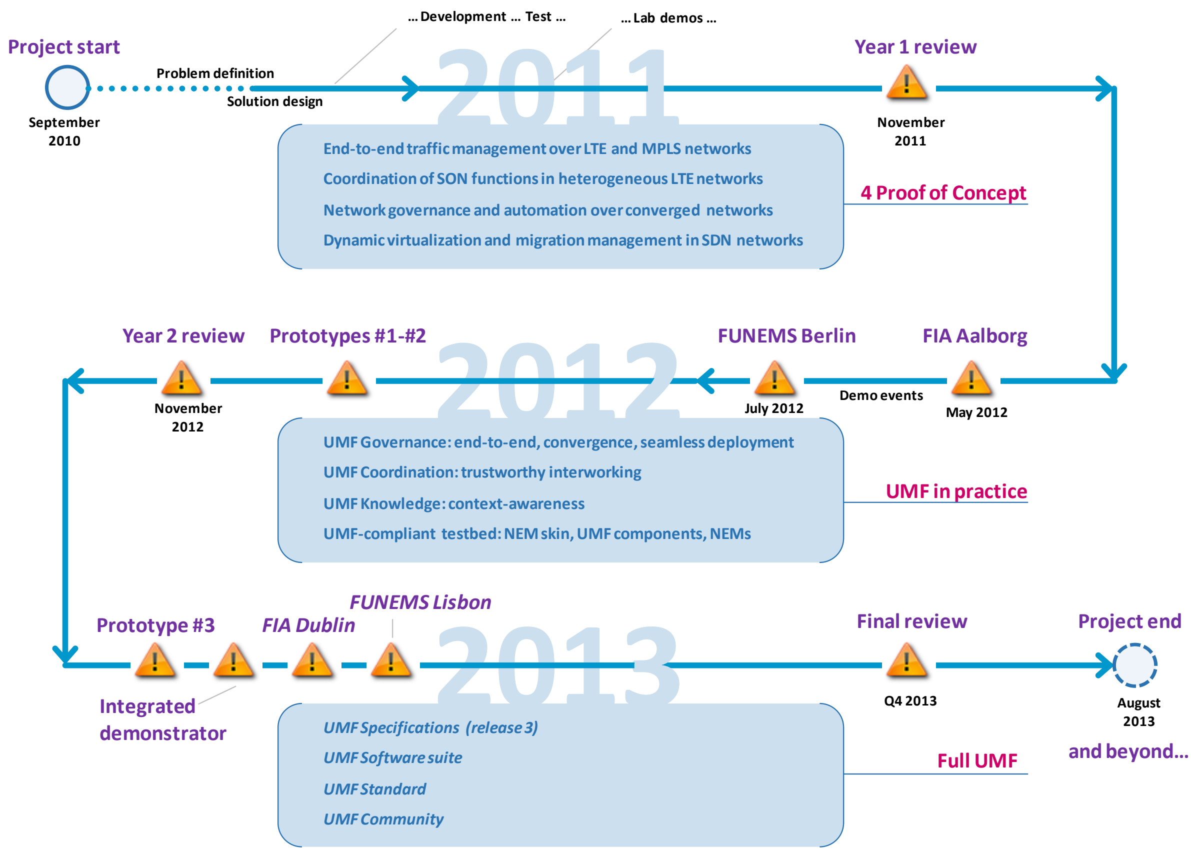


Figure 2 : UniverSelf experimentation timeline

In the context of the project, the criteria used for qualifying an experimentation as a "UNIVERSELF Prototype" are:

- Must be a prototype, not a simulation.
- Must solve a precise, problem (UC reference problems).
- Must contain one or more NEMs, which means a method solving a problem in a given specific technology/context.
- Must have a precise scenario (workflow/scripts).
- Must comply with the UMF specifications: details of certification should be considered.
- Must be evaluated/benchmarked (performance, functionality, UMF compliancy...)

An integrated portfolio

The aim of the project portfolio is to provide a comprehensive and consistent view about the solutions and technologies developed within the UniverSelf project, their constituting elements, their relationships and respective development levels. The portfolio presents an overall and integrated view about the solutions –i.e., the UniverSelf answer. The project portfolio is a tool useful to show the industry impact, feasibility, and relevance. The portfolio is currently structured around three dimensions: the capability levels (of a NEM or core mechanism), the development lifecycle, and the application domain(s).

Please note that the portfolio is currently still under construction at the time of edition of this leaflet.

The UniverSelf project produces two principal pieces of solutions tightly related: the Unified Management Framework (UMF) and the Network Empowerment Mechanisms (NEM). These elements constitute the base of the project portfolio. The various combinations (or packaging) of these elements (UMF core functions and mechanisms, NEMs) constitute the project integrated solutions. As example, UMF core functions, mechanisms and specific NEMs are combined together to provide an integrated solution to the use case 1 on self-diagnosis and self-healing for VoIP and VPN services. Similar examples exist for the other project use cases, and infinity of variations can be imagined to address the different problems and use cases.

By definition, the UniverSelf portfolio is limited to the project scope (set of use cases defined and technologies covered), however the approach taken in the project is to provide a unified and extensible technology that can adapt to other use cases (out of the initial scope of the project) and to other technologies with zero or minimal modification to the UMF and its specifications. The solutions developed are modular, composable, extensible, interoperable, and can interwork with legacy systems. The IT/telco environments where they can be deployed have been evaluated, tested, and benchmarked, Examples of interworking and deployment (options) are also described as part of the project portfolio documentation together with other elements (or views) related to the different solutions such are the applicable business reference use case(s), problems...

The UMF and the NEM concepts can be briefly described as follows:

A NEM achieves a self-management function (a closed control loop), with a specific purpose:

- an operational problem to be solved,
- a performance objective to be achieved,
- a network segment or service infrastructure to be targeted.

A NEM is therefore a kind of atomic component for autonomic network management. The parallel can be made with the usual design approach of using the relevant method to solve a concrete operational problem in a specific networking environment. Thus a NEM is defined by the combination of a method, an objective, and a context, such as for example, the use of Bayesian inference for fault diagnosis in FTTH environments, or the use of genetic algorithm for interference coordination in LTE networks.

Then, when a NEM is deployed or in use within an operator infrastructure, it has to deal with a set of actors: its environment: the operator, the network/service equipments, the legacy management systems and also the other NEMs. So, if we target a seamless deployment and trustworthy interworking of a large number of NEMs, we need more than just NEMs. Specifically, we need:

- Tools to deploy, drive and track progress of NEMs which highlight the need for Governance/Human-to-Network tools.
- Tools to avoid conflicts ensure stability and performance when several NEMs are concurrently working which highlight the need for Coordination/Orchestration mechanisms.
- Tools to make NEMs find, formulate and share relevant information to enable or improve their functioning which highlight the need for Knowledge management.
- Tools to Allow NEMs getting monitoring data and enforcing configuration actions at equipment level which highlight the need for specific adaptors.

Three challenging research topics are outlined above: Governance, Coordination and Knowledge management, which constitutes the core of the UMF.

PROOF OF CONCEPT

This section describes UniverSelf Prototype 2, in terms of its context and implementation aspects. UniverSelf Prototype 2 is a subset of Use Case UC7 Network and Service Governance [1]. While the Use Case aims to demonstrate a policy based governance approach to manage different types of network segments (namely Fiber-To-The-Home and DSL wireless) and network mechanisms, this Prototype 2 focuses only on the wireless testbed and the governance of coordination mechanisms in LTE-Advanced networks with relay stations.

From User Requirements & Operator Goals to ....

Automated Actions in the Network

Context

Telecommunication operators face the increasing challenge of providing higher levels of broadband access to more demanding customers. Therefore, operators have the need to adapt their operations in order to reduce the time to market and the network maintenance costs, while at the same time increasing the customer satisfaction. The management of the physical network infrastructure to enable high-quality new services is an increasingly critical part of the operational processes. In this context, solutions for the automation of the network operation as the ones provided by autonomic networks are becoming more and more important and strategic for network operators: self-optimization functionalities enable better reactivity and hence performance gains; self-diagnosis and self-healing lead to a faster isolation of the failures, automatic mitigation of the impact and implementation of repair actions. These improvements should be accompanied by a transformation in the business definition of services and the actual deployment at the network level.

The UniverSelf Prototype 2 aims at solving the problem of providing operators with automated decision oriented operational tasks for governing the autonomic network, thus reducing the human intervention for service & network configuration/deployment while fulfilling the quality of the services committed to the customers. To this end, the prototype targets to demonstrate the feasibility of a policy-based network management approach, governing a mobile network segment, based on a Wi-Fi connection on DSL network. At the same time, the prototype has developed self-* functionalities (e.g. self-monitoring, self-diagnosis and self-healing) which enables the early detection and resolution of network and service problems. The detailed analysis of the Use Case problems gave as a result a collection of requirements for governance and support of self-* capabilities that were summarized in Deliverable D4.2 [2].

The solution was designed based on a set of software agents embedded into the wireless hardware elements. These agents provide the autonomic functionalities of self-monitoring, self-healing and self-optimization. All of them receive instructions from a Governance layer, composed of two main elements: a Human to Network Interface, that has being designed as a friendly graphical user interface for the human operator to interact with the network; and a Policy Derivation and Management function, able to translate the high level objectives set by the human operator to low level policies, to be enforced onto the network.

The basic scenario described above has been extended in order to demonstrate that the same implementation of the governance framework can be used for the management of SON coordination functionalities in a LTE-Advanced network. The underlying SON mechanisms were originally designed for Use Case UC4, SON and SON collaboration according to operator policies. The ultimate goal is to demonstrate the coordination of different SON functionalities to ensure scalability but still achieving the expected performance gain, and to showcase that these operations can be instructed to achieve the goals of the operator.

A running implementation

This section describes the implementation and deployment of UniverSelf Prototype 2. First, the UMF components that are instantiated in this Prototype are described [3], [4]. Then, the testbed and the deployment architecture are detailed. And finally, a story line of the demonstration of the Prototype 2 is provided.

Starting with the description of the implementation work, in order to solve the problems described in the previous section, a set of NEMs (Network Empowered Mechanisms) has been developed and deployed in the testbed. The goal of these NEMs is to enrich the network elements with autonomic capabilities. Routing for MPLS Traffic Engineering NEM and Self-Healing Mechanism for Cell Outage Management NEM act on the wireless testbed, while Coverage and Capacity Optimization NEM have been developed for the simulated LTE Radio Access Network:

- Routing for MPLS Traffic Engineering NEM has been designed for providing dynamic routing adaptation of traffic flows across network elements. It has been implemented in Matlab, enriched with a Graphical User Interface for the visualization of the network topology. The evaluation of this NEM, that uses Evolutionary Techniques, demonstrates that the multi-point search in the area leads to fast convergence to near optimal solutions, and has been proved to give better results than other well known optimization algorithms such as the constrained non linear optimization technique. The details of this approach are described in depth in Deliverable D3.5 [8].
- A second NEM in this prototype is the Self-Healing Mechanism for Cell Outage Management NEM, that aims to adjust the transmission power of neighbouring base stations in case of a failure in one of the access points. This algorithm has been implemented and deployed in Soekris devices (Linux-based programmable Access Points), and it has been extended with simulation results that are described in depth in Deliverable D3.5 [8].
- Coverage and Capacity Optimization (CCO) NEM finds the appropriate OFDM resource and power allocation in the target cell, to maximize the throughput in the target cell (capacity optimization), while target cell's users experience acceptable channel quality (coverage optimization), by taking into account the target cell context (load, radio conditions etc.), the amount of available resources and the requested channel quality that the target cell's users should experience.

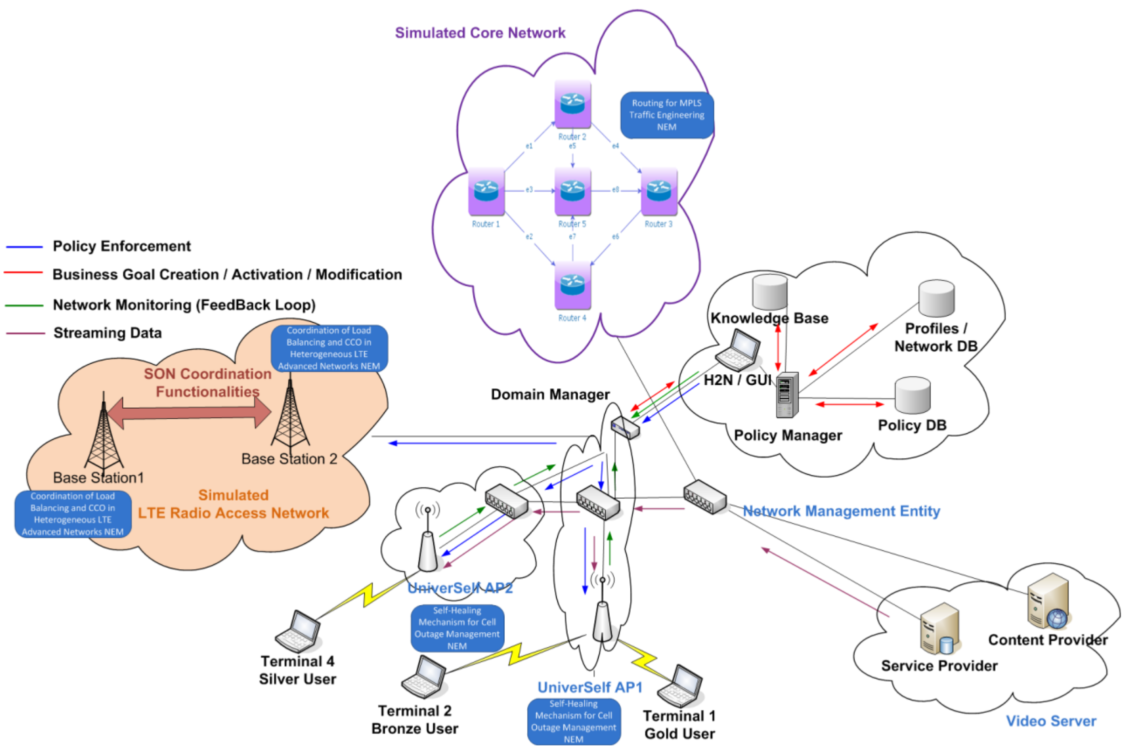


Figure 2: Testbed for UniverSelf Prototype 2

The above mentioned NEMs can be governed via the Governance core mechanism (GOV), using exchange information through the Knowledge block (KNOW). In the Governance block, a subset of functions and operations have been implemented in Java programming language for UniverSelf Prototype 2, in order to enable the dynamic definition of business goals, their translation to policy rules, the enforcement of the derived rules/actions and their evaluation. This involves the Human to Network (H2N) related function, the Policy Derivation & Management (PDM) function and its Policy Translation operation, Policy Assessment operation and a Policy Repository. The KNOW core block supports the necessary information exchange and storage required for the operation, namely the Interaction with Information Sharing, Information Collection & Dissemination, Information Storage and Indexing functions.

The above described NEMs and main core functions have been implemented and fully tested in the testbed shown in **Figure 2** for UniverSelf Prototype 2. The wireless testbed comprises a set of mobile devices and programmable access points (Soekris devices). They are based on Geode single chip processors with an x86 architecture and target to run open source operating systems, like FreeBSD, OpenBSD, NetBSD and Linux. The key characteristic of these devices is the provision of greater programming flexibility than dedicated network devices. The access points provide Wi-Fi connection to a set of terminals. Servers simulating a service provider and content provider serve video and http to the mobile devices. In addition, a simulated core network, comprising routers as well as a simulated LTE Radio Access Network comprising macro- and relay stations have been implemented. Both of these simulated networks were integrated with the wireless testbed.

This Prototype 2 showcases a scenario where the governance framework is used to govern the two different network segments (Wi-Fi and LTE) by means of high level objectives. In the Wi-Fi testbed, the H2N is utilized to specify the operator's parameters (supported services, user classes, available levels of availability, reliability, speed and security, etc) and a set of predefined business goals related to the different classes of mobile devices. Then, traffic is injected considering a video service in the mobile terminals. The system evaluates the parameter values using a threshold-based approach and takes into account the defined business rules for a given user class (e.g. A Gold class user consuming a Streaming service should experience "Excellent" availability, "Excellent" reliability and "Excellent" speed). The outcome of this procedure is rerouting the traffic flows the core network (Using the Matlab Genetic Algorithm toolbox). In addition, a comparison is made between the following algorithms: Constrained Non Linear Minimization technique (FminCon), Genetic Algorithm and Particle Swarm Optimisation (PSO) algorithm. Then, one of the users is dynamically associated to the neighbouring UniverSelf Access Point (AP), in order to fulfil the QoS level described in the SLA of the customers, which starts to decrease due to the traffic injection. Finally, one of the two APs is provoked to have a failure. The system 'understands' these failures and triggers the transmission power increase of the neighbouring AP to handle the users.

On the other hand, in the simulated LTE Radio Access Network testbed, a high link usage event occurs in operator's cellular network (LTE). This event triggers the automated translation of business goals to policy rules triggers the coordination between cells for load balancing. As an outcome, the link usage is fairly distributed to neighbouring relays.

In summary, UniverSelf Prototype 2 has been deployed and tested in a wireless and a simulated LTE Radio Access Network testbed, where it has been demonstrated that autonomic functionalities can be embedded into network elements, improving the QoS offered to the customer. Moreover, these autonomic NEMs can be effectively governed through the UMF core blocks using high level objectives instead of technology specific commands.

KEY RESULTS AND FINDINGS

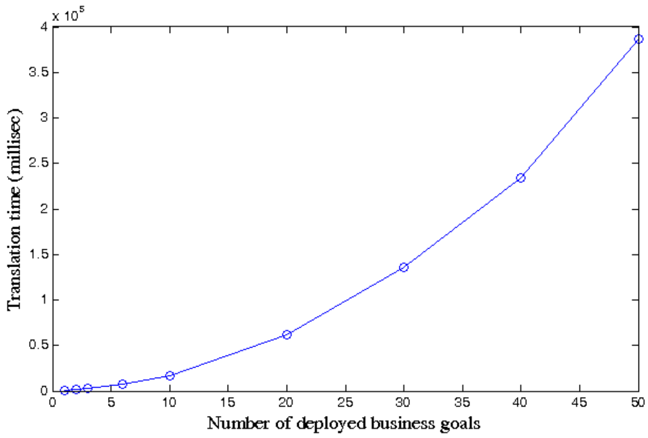
This prototype is mainly based upon UC7 but at the same time it comprises parts of UC4 and UC6 as well. The table below analyses the use cases problems that were addressed and the functional requirements that were validated using each demo component of UC2 prototype [6][2] . As regards the functional requirements, the ones that were extracted by the QFD analysis were considered based on deliverable D4.2 [2]. In addition, the table illustrates the mapping of the demo components to UMF blocks and respective functions and NEMs.

Demo Component	Use Case Problem	Functional Requirement	UMF block/NEM
Governance framework	UC7-1, UC7-6,	FR7.7, FR7.8, FR7.19,	GOV (PDM function, H2N function)
Communication mechanisms between Gov. Framework & deployed solutions	independent	FR6.16	KNOW (Information Collection & Dissemination, Information Storage and Indexing functions)
Genetic Algorithm for MPLS routing	UC6-3, UC6-5,	FR6-16, FR6-15	Routing for MPLS Traffic Engineering NEM
Self-healing & Handover mechanism	UC7-5, UC4-3	FR7-8, FR4-3	Self-Healing Mechanism for Cell Outage Management NEM
SON coordination mechanism	UC4-1, UC4-2, UC4-3	FR4-3, FR4-4, FR4-9	Coordination of two SON functionalities in a LTE-Advanced heterogeneous network with macro- and relay stations NEM

In order to implement this prototype and align with the architectural work of UMF, a roadmap has been set for the implementation, integration and testing of the components to the proof-of-concept tested and its continuous alignment with UMF. The outcome of this work was the first version of this prototype that was demonstrated in Y1 Review. This version comprised the elements listed in the table except from the Coordination of two SON functionalities in a LTE-Advanced heterogeneous network with macro- and relay stations NEM. The latter was available and has been incorporated in the second version of the prototype. In this version, the Routing for MPLS Traffic Engineering NEM has been enhanced with additional techniques (PSO – Particle Swarm Optimisation). Special focus has been put in aligning the prototype with the UMF architectural work [7]. Specifically, REST interfaces have been developed for the communication between the GOV blocks and the implemented NEMs and gradually NEM mandate and manifest parameters have been incorporated [4]. This second version of the prototype has been successfully demonstrated during the Future Internet Assembly 2012. In the following text, some key results obtained from the evaluation of UC7 are analysed in more detail.

<u>Governance Framework</u>

The developed component enables the operator to define business policies using a language similar to natural language. Next the translation of the business goals is applied using the policy translation framework [5]. The innovation of the latter is based on: a) its ability to co-manage network and service, b) the use of policy templates to constrain the translation process to only meaningful translations, c) the classification of business goals based on KPIs (Key Performance Indicators), d) the utilisation of ontologies and ontological rules to all steps of policy translation. More details are provided in deliverables D2.2 and D4.6 [4], [3].



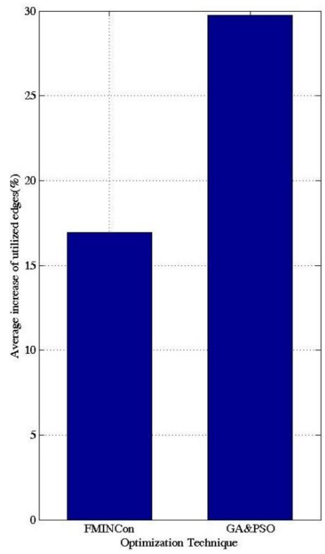


Figure 3: (a) Policy translation delay, (b) Average increase of utilized edges over the 100 topologies

The scalability of the proposed policy translation process has been examined to quantify the translation delay of the business goals versus the number of the generated policies. **Figure 3** (a) presents the results based on measurements conducted in the testbed. Results show that the delay introduced by the translation process is insignificant for a low number of deployed policies (e.g. in case of 3 policies the translation delay is around 2.5 sec), while it highly increases in case of a high number of generated policies (e.g. in case of 50 policies the translation delay is around 6 min). However, since this procedure is to be executed offline and during the system bootstrap, the introduced delay does not affect the operation of the overall system. Moreover, the introduction or update of the defined business goals does not require the re-execution of the whole translation procedure; the sole evaluation and translation of the particular business goal should be only realized.

Genetic Algorithm for MPLS routing

The implementation of the Routing for MPLS Traffic Engineering NEM proved that evolutionary techniques achieve better load distribution over the core network. The Genetic algorithm and PSO produce similar results and outperform the FminCon routing algorithm. **Figure 3** (b) highlights the outcomes of our experimentation. More specifically, we have tested 100 random topologies and the results show that Evolutionary Techniques obtain better performance in terms of edge utilization in approximately 40% of the tested topologies. FminCon performed better in approximately 30% of the tested topologies; in addition, the rest 30% of topologies resulted in similar performance for both approaches. Finally **Figure 3** (b) shows that FminCon achieves 15% average increment of utilized edges for the topologies resulting in better performance compared to the other algorithms. The utilized edges are increased significantly (i.e. 30% increment) for the cases that Evolutionary Techniques result in optimized performance.

Self-healing

In the implementation of the Self-Healing Mechanism for Cell Outage Management NEM, the parameter that is optimized is the Tx power of the neighbouring eNodeBs. The self-healing algorithm is based on fuzzy logic, which is a problem-solving methodology based on control system theory. This algorithm takes as input a set of related parameters and exports as output the new Tx power of the neighbouring eNodeBs in order to compensate for the cell outage. More specifically the inputs for the fuzzy logic system are the following:

- Percentage of Tx Power (current Tx Power / max. allowed Tx Power)
- Cell load
- # of MTs assigned
- Average RSS (RSS of neighbouring eNodeBs and MTs for this eNodeB based on a specified weight)

Then a set of rules is defined for transforming the input variables to output ones. For example, if the NeighbouringRSS load is high (close to 1) then the TxPowerAdjustment is low, despite the TxPowerPercentage value. The integration of this algorithm in the testbed proved its applicability, resulting in Rx power increasing in case of AP failure. Besides the implementation of the self-healing mechanism in the testbed, simulations were conducted, considering a grid topology of 9 APs and 49 randomly distributed mobile terminals (MTs). After the central AP failure where 7 MTs are affected (disconnected), the created coverage gap is covered by the neighbouring AP based on the calculations of the proposed fuzzy inference system. The evaluation metrics for the algorithmic and power maximization case are shown in **Table 1** (a). The adjusted transmission power levels of the compensating APs are presented in **Table 1** (b). We consider that the maximum transmission power for the APs is 20dBm. Simulation results for this indicative grid topology of APs and randomly positioned MTs show that our algorithm can provide a good solution for the coverage-interference trade-off problem while ensuring sufficient load fairness among APs. More details are available in D3.5 [8].

Number of MTs	Evaluation Metrics					
	Load balance index (β)		Reconnected MTs' percentage (P_r)		Total Interference Indicator (I_t)	
	Self healing Algorithm	Power Maximization	Self healing Algorithm	Power Maximization	Self healing Algorithm	Power Maximization
49	0.711	0.650	100.0	100.0	2.152	2.662

AP id	Tx Power (dBm)
2	16.9
4	15.0
6	15.2
8	17.1

Table 1: a) Evaluation metrics, b) Tx power levels and assigned channel for the compensating APs after the fuzzy inference system calculations

<u>SON coordination mechanism</u>

This mechanism presents the coordination of two SON functionalities in a LTE-Advanced heterogeneous network with macro- and relay stations. Following the evaluation of a high link usage event occurring in operator's cellular network (LTE), the remedy action of SON Coordination between cells for load balancing is triggered. Finally the link usage is fairly distributed to neighbouring relays as shown in the figure below. In addition, the network coverage of the relay stations in increased.

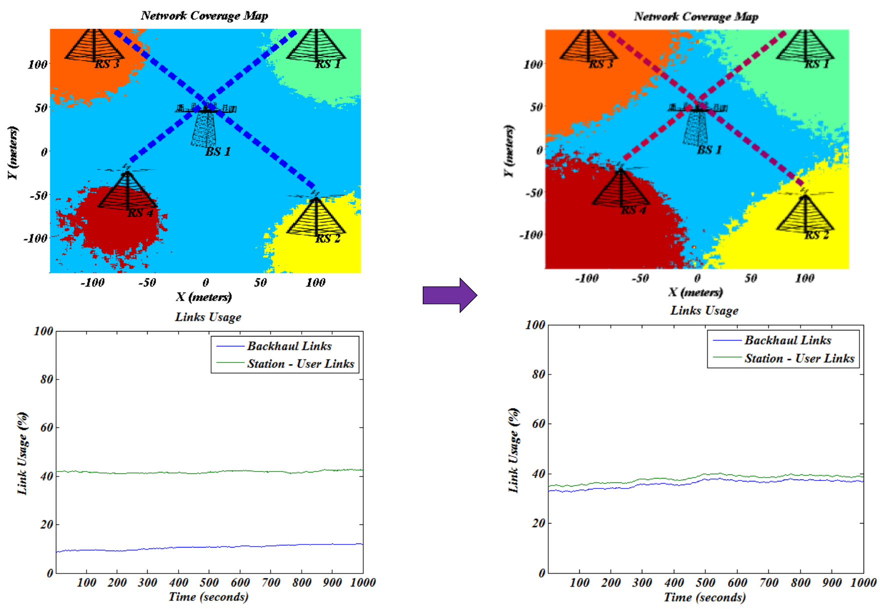


Figure 4: Network Coverage Map and Link Usage before and after the application of the algorithm

This prototype demonstrates that the UMF specifications delivered by WP2 can be effectively implemented to govern NEMs with independence of the underlying technologies. The Unified Management Framework does not impose any implementation mechanism, but ensures the efficient management of autonomic network and services as long as the proper interfaces are used. Vendors can then deliver they own NEMs without exposing the inner details of their solution, and operators can still govern those NEMs with their UMF-compliant management system.

In the current telecommunication context of high competitiveness and need of cost reduction, solutions for the automation of the network operation as the ones provided by autonomic networks are becoming more and more important and strategic for network operators. With the usage of self-optimization functionalities which control network resources, as the ones achieved in this use case, better reactivity and hence performance gains are achieved. Self-diagnosis and self-healing lead to a faster isolation of the failures, automatic mitigation of the impact and implementation of repair actions. The solution provided in this Prototype 2 shows how the QoS offered to the end-user can be improved by preventing problems and lowering the Mean Time-to-Repair, which leads to an increased service availability. This translates into a reduction in the cost per service and the need of specialized personnel, both of which have an important impact in the company OPEX. Furthermore, the improvement in the QoS offered to the customers should lead to reduced churn rate and potentially increased revenues.

All of the above raises the question of how can the operator maintain its control over the autonomic network. The implemented governance framework revolutionizes management of large heterogeneous network infrastructures, since it enables network operators to automate end-to-end management of their services assuring operational processes like monitoring and diagnosis. This plays an essential role in alleviating human intervention and decreasing operation complexity and costs of future networks. With this in view, network operators will thus have the opportunity to further enhance the quantity and quality of services across multiple heterogeneous domains meeting customers' expectations and further improving customer experience.

One of the main concerns for operators when considering the rollout of an autonomic network is the management of legacy networks. The UniverSelf Prototype 2 has proved that UMF and NEMs can be used to seamlessly govern both types of network elements. On one hand, the software in the wireless testbed is embedded into the Soekris access points, as it would be in a fully autonomic solution.

In summary, UniverSelf Prototype 2 has demonstrated that UMF can effectively manage both autonomic and legacy networks from a high-level point of view. This is achieved with independence of the implementation details and underlying technological choices that are left to NEM developers. This proof of concept has demonstrated that self-* capabilities can be really developed for different types of network segments. The evaluation has been performed on hardware testbeds, with the aim of helping to convince network operators of the feasibility and advantages of the deployment of a UMF compliant autonomic network.

Future plans include the enhancement of the prototype as follows: a) fine-tuning the governance framework with conflict resolution mechanisms, b) integration with the FTTH testbed provided by Telefonica and incorporation of the FTTH Bayesian Monitoring and Diagnosis NEMs, c)extension of the self-healing mechanism integrating a simulated Self-Healing Mechanism for Cell Outage Management NEM, d) integration with the wireless testbed by VTT incorporating the Self-Healing Mechanism for Cell Outage Management and e)full alignment with UMF Release 2. This work is ongoing at the moment and a major part of it will be demonstrated in forthcoming events (e.g. Y2 Review).

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