Chapter 7

VII. CONCLUSIONS

Section VII.1 – Summary

The work presented in this thesis document was oriented towards designing, implementing and evaluating a framework for the management of heterogeneous active, programmable and passive networks.

The starting point of the work developed was the expertise gained by the author with its collaboration in the FAIN project, more specifically in the management architecture. The MANBoP framework proposed in this document shares many concepts with the management architecture in FAIN, although the scope of the MANBoP framework has been broadened. Moreover, some of the management mechanisms designed in FAIN have been changed with the goal of overcoming certain problems that these mechanisms had. For these reasons, although MANBoP could be seen as a continuation of the FAIN's management architecture, the broadened scope and the different approaches followed in certain mechanisms (i.e. extensibility and delegation mechanism), have driven us to a proposed innovative solution significantly different from the one in FAIN.

Additionally, the work in FAIN has given to the author of this thesis a deep knowledge on the state of the art in the management of active networks that has been of great importance for the realisation of the current proposal. This knowledge has been updated, described and analysed in the document. Furthermore, we have also compared the goals and approaches of the different state of the art projects against those of the MANBoP approach.

Before starting the design of the proposed solution, we set a number of initial requirements that the framework had to handle. Many of these requirements were due to the fact of managing active and programmable networks, although there were others that had their origin in the initial goals of the framework or just on the basic functionality of a management system. These requirement have driven the design and proof-of-concepts implementation of the proposed solution.

The proposed MANBoP framework design is independent of the management level at which a MANBoP instance is running (e.g. network-level or element-level) and of the underlying devices (e.g. managed devices or lower-level MANBoP instances). Then, when functionality from a new functional domain is needed, the system automatically downloads the

appropriate components that implement such functionality at the appropriate management level and to interact with the corresponding managed devices. Such a design allows both the management of heterogeneous networks and the simple creation of different management infrastructures.

Furthermore, the MANBoP management framework design described in depth in this document contains all the management functionality needed to work as a complete solution. It includes even a proposed solution for those fields that are considered as out of the scope of this thesis, as the traffic engineering functionality or the policy conflict check mechanism. Nevertheless, in the proof-of-concept implementation these fields have not been implemented or, in some cases, a very thin implementation has been realised.

The implemented functionality has been chosen to proof and evaluate the main concepts of the proposed solution. All the functionality that is derived from the project objectives and requirements has been implemented. Particularly interesting is the implementation of the delegation mechanism of the framework. Such implementation takes advantage of the XML validation properties against XML Schemas to realise the authorisation of the user requests against his access rights.

Another relevant comment about the implementation developed is that it has been targeted to fulfil the proposed design and evaluate the framework concepts. Hence, the implementation has not been targeted towards the performance of the system, although we have tried not to leave it out neither.

Finally, based on the proof-of-concepts implementation developed we have run several scenarios in order to evaluate the proposed solution concepts. More specifically, we have designed two scenarios oriented each one towards assessing particular aspects of the proposed solution. The first scenario was focused in providing all the data that might be needed to analyse the functional requirements set over the expected solution. On the other hand, the second scenario was targeted towards the assessment of the system scalability.

All data recompiled from running the scenarios have been carefully analysed and compared with data from other projects, more specifically from the FAIN project, when this was possible. From the data analysis we have extracted and argued a number of conclusions about the proposed framework.

In the following section we retake the recompiled data and other remarks to assess and analyse the work developed in this thesis and the proposed solution. In the last section we elaborate around the future work that can be developed to enhance both the design and implementation realised for the solution proposed in this thesis.

Section VII.2 – Assessment and analysis of the work developed

The MANBoP framework proposed in this Thesis presents a number of novel features that either fill gaps not yet covered in the current state of the art research projects or suggest new solutions to specific problems. The following points summarise these novel features that might have an impact over the current state of the art.

i) One of the novel features of the proposal is the capability of allowing a simple creation of the management framework that best suits the needs of the network operator. Indeed, the creation of whatever management infrastructure is as simple as starting the MANBoP instances that will form such infrastructure with the correct configuration files (the content of these files is described in detail in appendix B). The functionality designed and implemented will do the rest for correctly finding and interacting with both other MANBoP instances within the infrastructure and managed devices.

ii) A second aspect that is not explicitly considered in almost any management approach to active and programmable networks is the fact of supporting heterogeneous types of devices. There are several research efforts dealing with the support of heterogeneous passive networks but they do not fit the requirements introduced by active and programmable networks. The MANBoP framework supports this feature. Moreover, from the evaluation results we have seen that the MANBoP framework is not only capable of supporting any type of active, programmable and passive node but it profits the facilities of each type of device to enhance the management performance.

iii) Another novel facet of the proposed solution is the delegation approach taken. The use of the optimised XML validation tools for authorising users' XML policies against their access rights, represented as restricted XML Schemas, simplifies enormously the delegation solution. Furthermore, the authorisation process, the one used with more frequency among all delegation processes, is left to XML validation tools freely available and specifically implemented to achieve an efficient validation algorithm. The key aspects that differentiate the MANBoP delegation approach from other state of the art delegation approaches is the simplicity of the approach taken and the fact that the authorisation process is left to specialised code.

iv) The fourth remarkable aspect of the framework is the extensibility mechanism designed and implemented in the proof-of-concepts. As argued in the evaluation chapter the extensibility approach suggested in MANBoP serves to

dynamically install, when needed, not only the component implementing the requested functional domain but also the component that implements that functional domain at a particular management level and to work over a concrete underlying device. Hence, the extensibility mechanism plays a key role also in both the support of heterogeneous networks and in allowing the simple creation of different management infrastructures. Indeed, the originality of the extension mechanism is not the mechanism itself but how it supports these functionalities. Furthermore, we have tried to optimise the management functionality that must be dynamically downloaded to reduce it to the minimum.

v) The last point that might potentially impact the current state of the art in the field, as we are not aware of any research project explicitly supporting this property, is the support for the dynamic addition and removal of nodes. This property only has sense when the management framework includes network-level functionality (at the element level the support of this feature is straightforward). This framework feature facilitates the evolution of the network operator's network by allowing the progressive replacement of legacy devices while keeping both the management infrastructure and the policies that dictate the behaviour of the entire network.

On the other side, there are also a number of issues that could be enhanced in the design and implementation of the framework. In brief, hereafter we enumerate which are the weakest aspects of the proposed solution.

i) Probably the weakest aspect of the proposed solution is the system's security. The reason is that, as commented several times along the document, the security issues of the system have been considered from the beginning as out of the scope of this thesis. The main arguments for this decision are that first, in general, the basic security mechanisms that the framework would need are not really a challenge in terms of research while on the other hand they consume a lot of design and implementation effort. Second, security does not have almost any influence in achieving and evaluating the main objective of this thesis: the design and implementation of a framework for the management of heterogeneous active, programmable and passive networks.

ii) Another facet of the proposed solution that could be enhanced is the Code Installing Application (CIA) system. Although considered from the beginning as a system separated from the MANBoP framework, it is undeniable that both systems are closely linked. Even more, the performance of the MANBoP

framework is affected by the performance of the CIA system. Thereby, a better design and implementation of the CIA system could lead to a general enhancement of the framework performance.

iii) A third point that can be enhanced in the MANBoP framework is the design of the traffic engineering and conflict checking functionality. In both cases, the proposed design has been provided for sake of completeness as they are considered as out of the scope of this thesis. The goal of the mechanisms designed is just to show the feasibility of the required functionality by providing one possible solution. Nevertheless, a design, together with the corresponding implementation, of efficient traffic engineering and conflict checking mechanisms would provide an added value to the MANBoP framework.

iv) The last issue is the framework implementation. The implementation realised for the proof-of-concepts of the proposed solution is oriented towards that goal: proving the concepts of the solution. Thereby, the implementation covers the required functionality to evaluate the most important concepts and requirements of the architecture. However, a new implementation of the framework targeted towards achieving an optimum solution in terms of performance could add value to the final system.

In the next section we suggest future work that can be developed to enhance these weak points and also to extend the proposed solution to other fields.

The concepts and ideas followed in the MANBoP framework, some of them shared with the FAIN project have already been presented, argued and analysed in a book as well as in magazines and congresses:

- Book:

  i) Co-author and editor of the fourth chapter of the book "Programmable Networks and their Management" published before January 2004 by Artech House Books with ISBN 1-58053-745-6. The chapter is titled "Programmable Network Management & Services – Background".

- Magazines:

  i) Tan, A. Galis, J. Serrat, J. Vivero, "Supervision of Active and Programmable Network", HTE Communications Magazine, February 2003, pag.48

  ii) C. Tsarouchis, C. Kitahara, S. Denazis, J. Vivero, E. Salamanca, E. Magaña, A. Galis, J. L. Mañas, Y. Carlinet, B. Mathieu, O. Koufopavlou, "Policy-Based Management Architecture for

Active and Programmable Networks", IEEE Network, May 2003, Vol.17, No.3

- Congresses:

i) A. Galis, J. L. Mañas, Y. Nikolakis, J. Serrat, A. Tan, J. Vivero, "Management of Active and Programmable Networks" DRCN2001 7-10th October 2001, Budapest

ii) A. Galis, A. Tan, J. Serrat, J. Vivero, "Policy-based Network Management for Active Networks" ICT2001 4-7th June 2001, Bucarest

iii) J. Vivero, E. Salamanca, J. Serrat, J. L. Mañas, Y. Nikolakis, A. Tan, "Network Management in Active Networks: Issues and Proposed Solutions" SCI2001/ISAS2001 22-25th July 2001, Orlando

iv) J. Vivero, E. Salamanca, J. Serrat, "Active Policy-based Management", presented at Opensig2001 24-25th September 2001, London

v) C. Kitahara, S. Denazis, C. Tsarouchis, J. Vivero, E. Salamanca, C. Klein, J. L. Mañas, A. Tan, A. Galis, C. Brou, M. Urios, K. Sugauchi, "Delegation of Management for QoS Aware Active Networks", CQR 2002 14-16th May 2002, Okinawa

vi) J. Vivero, A. Tan, J. Serrat, E. Salamanca, A. Galis, C. Kitahara, C. Tsarouchis, S. Denazis, "The FAIN Management Framework: A Management Approach for Active Network Environments" ICON2002 27-30th August 2002, Singapore

vii) A. Tan, A. Galis, J. Vivero, E. Salamanca, J. Serrat, C. Tsarouchis, C. Kitahara, S. Denazis, "A Policy-based Framework for Delegated Management of Active Networks" Openarch 2002 28-29th June 2002, New York

viii) A. Tan, A. Galis, J. Vivero, J. Serrat, "Ad Hoc Networks with Active Technology: A Synthesis Study" Workshop on Ad hoc Communications September 2001, Bonn

ix) J. Vivero, J. Serrat, "MANBoP: Management of Active Networks Based on Policies", IPOM 2002, October 2002, Dallas.

x) A. Tan, A. Galis, J. Vivero, E. Salamanca, J. Serrat, C. Brou, C. Tsarouchis, C. Kitahara, S. Denazis, J. L. Mañas. "A Network Management Approach for Active Networks", Poster in IWAN 2002, December 2002, Zurich.

xi) J. Vivero, J. Serrat, "Management of Heterogeneous Active Networks Based on Policies", Poster in IWAN 2002, December 2002, Zurich.

Section VII.3 – Future work

The work developed in this doctoral thesis can be used as starting point for other lines of research related with the management of heterogeneous networks. Some of them could be related with the enhancement of proposals in this thesis and others might identify new fields where the developed concepts might be also applied. Also new technologies might be explored to be used as basis for finding out new ways of achieving the initial objectives.

Hereafter, we list possible future lines of work that might be followed to either extend or enhance the proposed solution.

i) Security is, likely, the most straightforward line of work to be developed in an initial phase. Secure the management system would be essential to exploit it commercially. The basic security mechanisms that could be added to MANBoP are, first, a user authentication mechanism based on credentials with a higher security than that offered by a single user name and password. Closely linked with this authentication mechanism is the need of encrypting management commands (including interactions with the Naming Services) and policies. The encryption of policies is fundamental, as they contain the credentials of the user whose resources are being modified by that policy. Finally, another basic security mechanism that could be applied is the avoidance of undesired accesses to all machines forming the management infrastructure, both code server and management stations. Obviously, further security mechanisms can be also considered as mechanisms for protecting the infrastructure against denial of service attacks or others.

ii) As explained before, the CIA system is another of the framework facets that can be enhanced with future work. Clearly, the main requirement for the CIA system is supporting the fastest possible component downloads. Future lines of work that can be explored to achieve this goal are on the one hand the enhancement of the parallelism of the code server. That is, the capacity of supporting many code requests at the same time and serve them in parallel. On the other hand, another line that can be explored is the speed up of the download mechanism itself by using new technologies for the code transfer. The use of simple technologies for the code transfer such as http and ftp, or their secure equivalents https and sftp, can be an interesting alternative.

iii) The performance of the MANBoP framework can also be enhanced by starting work aimed towards achieving an optimum implementation in terms of performance. One of the possible lines that can be analysed to enhance the performance of the proposed framework implementation is trying to achieve the maximum parallelism of the framework tasks by minimising those tasks that need to be done in a synchronised way, and hence sequentially. In this way, policy processing delay can be reduced when several policies arrive at the same time at the management station.

iv) Another field where some of the proposed concepts can be applied and evaluated in future work is interdomain management. More specifically, the concepts proposed for the management of heterogeneous networks and dynamic extension of the management functionality can be ported to the interdomain management field. The idea is that dynamically installable components do not necessarily need to interact only with lower-level devices. They can also interact with peer devices (other managers at the same level) and thereby support interdomain management functionality. Obviously, if peer devices were all MANBoP instances, the interaction would be simpler, but as with heterogeneous networks support, different components could be dynamically installed to interact with different peer devices, that is different types of interdomain managers.