Human Operator Perspective to Autonomic Network Management

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Abstract - **Autonomic Communications is a promising approach for the management of future networks, based on providing self-management and other self-x capabilities to the network elements. Network Governance approach aims to develop new methods for operators to efficiently manage this intelligent infrastructure, ensuring human-to-network communication. This paper presents an interview-based analysis of the expertise of human network operators in their network management activity and the derived requirements for the governance of a self-managed network from a human point of view. The requirements cover the aspects of trust, division of labor between human operators and self-x functionalities, self-x design and human-to-network interface.**

Keywords - autonomic networks; self-x; Network Governance; human operators; human factors.

I. INTRODUCTION

Future computation, storage, and communication services will be highly dynamic and ubiquitous: an already increasing number of heterogeneous devices will be used from different places to access a myriad of very different services and/or applications. Users' devices, smart objects, machines, platforms, and the surrounding space will be interconnected as a decentralized tree of resources, conforming dynamic networks of networks. The complexity of managing such a network presents a challenge for telecom operators.

Current operation support paradigms cannot effectively manage this situation; rather a new reliable, dynamic, and secured communication infrastructure with highly distributed capabilities is needed. The autonomic network approach envisions meeting these features, helping network operators to achieve the desired levels of dynamicity, efficiency, and scalability to manage current and future networks.

Autonomic computing was first introduced by Paul Horn as a solution to the increasing complexity in the management of IT systems [1]. The suggestion was to design and build future systems and infrastructures capable of running themselves and adjusting to varying circumstances by taking the massively complex systems of the human body as a model. In fact, the name "autonomic" was derived from the human autonomous system. This proposal was well accepted by the industrial and scientific community, and it was extended to other fields. Then, Autonomic Communications was born with the objective of providing autonomic behavior to network infrastructures [2][3]. The terms self-monitoring, self-diagnosis, self-configuration, self-healing, and in general self-x were introduced to denote the new capabilities of the network nodes to manage themselves without external intervention.

UniverSelf [4] is an EU-funded FP7 project with the aims of overcoming the growing management complexity of future networking systems and reducing the barriers that complexity and ossification pose to further growth. The project aims at consolidating autonomic methods of the future Internet into a novel Unified Management Framework. It also includes the design of a privileged, powerful and evolved human-to-network interface that will be used by the human operator for expressing their business goals and requests, thus shifting from network management to network governance. Network Governance approach is meant to provide a mechanism for the operator to adjust the features of the demanded service/infrastructure using a high level language [5]. These high level directives must be translated into low level policy rules that can be enforceable to control the behavior of the autonomous agents.

Since the new management or government framework is intended to be used by human network operators (HNOs), it is of utmost importance to produce solutions that are usable by human users and meaningful in the context of their work. Presently, it is not known how autonomic functionalities should be designed in order to be functional from the human operator's viewpoint. Thus, it is important to learn what the characteristics of the HNO work are from the perspective of these professionals and what the specific demands are that the work sets on human performance. Also the conceptions regarding autonomic tools should be elaborated. For this purpose, as part of the UniverSelf project, we have carried out a set of interviews to human operators of two European telecom companies. This paper describes the results of these interviews. In particular, HNOs' views of the network characteristics and network management, their knowledge on autonomic functionalities, and the impacts (both benefits and risks) they foresee after the potential deployment of a self-managed network are focused on.

The rest of this paper is structured as follows. Section II presents a deeper elaboration on the objectives of this work. Section III details the methods utilized in the interviews and the analysis of the answers. Section IV presents the results of this analysis, which are further refined in the discussion included in Section V. This section presents the requirements that were extracted from the interviews and grouped into

 ISBN: 978-1-61208-177-9

requirements on network maintenance and requirements on self-x functionalities. Finally, Section VI concludes the paper by summarizing the outcomes of this work and anticipating future work.

II. OBJECTIVE

The tremendous evolution of network technologies in terms of their design, capabilities, and capacities has not been accompanied by advancements of the same magnitude in network management solutions [6]. Therefore, network management depends currently on the abilities of HNOs, and it is still a widely unknown area with very little knowledge from the human network operators' perspective. The willingness of HNOs to accept the new autonomic networks may constitute one bottleneck in the transitional period from human-centered to autonomically manageable networks. In this direction, when a new technological solution such as a self-managing network becomes ready to be deployed in large scale, the role of the HNOs, the demands of their work and other possibly affecting factors should be addressed in order to guarantee a smooth transition phase from deployment to flexible and efficient every-day use.

An analysis showed that the strategy to manage network operability depends on the demands and possibilities of the situation that vary in the continuums of options available for network operations and the instability of the situation [7]. In this study, however, the key personnel that had access to both strategic and operational level was found to be middle level professionals. Regarding network operation, it has been claimed that the cause of a major failure in system operation is not an accident but a conscious choice that proves wrong in that specific situation [8]. This indicates that when studying network operation in an operational level, the whole working system must be taken into account. In Finland, a study has been performed about the dependability of IP networks, including also human factors research related to the meaning of human error in the work of a HNO [9][10]. It was found out, among other things, that the error resulting from the work of HNO may originate from a lapse or typo but may also be a side effect of the whole working system that has deficiencies in its functioning.

Our approach in the present study was to seek information by enquiring into the work of technical experts that are currently operating the network in different companies. The main objective was to get information on the work of the HNO and additionally on user acceptance, i.e., the factors that effect and ease the deployment of autonomic network solutions from the HNO point of view. The aim was to get information directly from the professionals who operate the network, avoiding managerial levels. This practical approach provided information about the insight of the user perspective on network operation. In short, interviews were double-faced: on one hand, they tried to get a picture of the general network management as perceived by a HNO; on the other hand, there was a set of questions aiming to extract their conceptions about self-x functionalities.

The objective of this document is to present the results, analysis process, and conclusion of the HNOs' interviews. From this analysis, general requirements on network automation can be extracted. These requirements can be used for guiding the design and implementation of the governance of future networks.

III. METHODS

The background approach of the interviews was based on Core-Task Analysis method [11]. The aim of Core-Task Analysis is to identify the core task of a specific work. Core task is the main result-oriented content of the work that can be derived by analyzing the objective of work and the demands that the objective lays on workers both in general and in specific situations.

Interviews were conducted in telecommunication companies participating in the UniverSelf project. The interviews focused on the perspective of a HNO performing network monitoring or some other corresponding work in the same level, lower than the one of a manager, so that the characteristics of the network as a target of work would become highlighted.

Interviews were conducted anonymously in the native language of the interviewee.

A. *Data gathering*

All but one of the interviews were performed in a meeting room at the company premises where only the interviewer and interviewee were present. One interview was performed over telephone.

The interview comprised of 40 questions. The questions were built on two main themes: a) work characteristics of a HNO as conceived by the human operator and b) opinions of the manageability of self-x functionalities. Interviews were conducted during April and May 2011. Results of 17 interviews, acquired from two European telecom companies, are presented. The duration of interviews ranged from 10 minutes to 1 hour 40 minutes, which is reflected in the variety of quality in the interview data.

All interviews were audio recorded. The recordings were later on transcribed and translated into English for analysis purposes, resulting in about 180 pages of interview material.

B. *Analysis*

The performed analysis was qualitative. As the interviewees did not form a representative or statistically significant sample of all HNOs, all replies are important. Thus, even if an opinion expressed by several interviewees was regarded as more general and was self-evidently taken into account, single replies may have acquired similar weight in the analysis process if the expressed conception included a clearly expressed idea.

The analysis took place in several phases. First, the transcribed interviews were grouped according to interview questions. Similarly, questions that needed to be scrutinized together as well as questions that produced similar replies were grouped together. Then, the core idea or main message in each interview reply was extracted. These ideas or messages are here called notions. In practice, a notion is usually a shortened version of the expressed opinion (reply). In some cases, interviewee presented more than one notion in the reply; then, the notions within the reply were categorized in more than one category. Thereafter, similarities among the notions were sought for. Investigating iteratively the notions and the possible similarities among them, similarities between notions became gradually more apparent and notion categories could be created. All the notions belonging to the same category have about the same core message from the perspective of that category.

When extracting the results from the analysis, several information sources, based on interview data, were simultaneously available and used:

- the classified notion categories and the notions themselves, collected question-wise
- the original replies for each question, collected question-wise
- the replies by each interviewee, collected interviewee-wise.

The notion categories were important in acquiring an overview of the replies. This information source was the most important due to the amount of information. Original replies were important if the validity of some specific reply had to be checked. The interviewee-wise information is important to know if some deviant or specific opinion is presented; for instance, if the interviewee had some specific occupation, (s)he may have produced replies different from other interviewees' replies due to this deviant working experience. When reporting the results, mainly notions and notion categories are used.

The interview data were classified according to general topics: (*1*) background information related to the work of the interviewees, (*2*) network characteristics as perceived by human operator, (3) interviewees' work with the network, and (*4*) conceptions of self-x functionalities.

Background information (above, class *1*) was used for validating the results so that it is known what is the source of the opinions and information gathered in the interviews.

Network characteristics and interviewees' work with network (above, classes 2 and 3) already tell what the work demands and difficulties are in network operation. Thus, even if the interviewees may not be expressive in the answers related to self-x functionalities, the demands the network sets for the human operator were expressed here. Work demands and difficulties revealed in these replies can be used for inferring in what way self-x could support network maintenance.

Opinions of self-x functionalities (above, class 4) tell directly how human operators assume the self-x could support network maintenance and what should be avoided when designing them.

Finally, the conceptions classified as above were interpreted in the light of the requirements the domain sets to the work and tools of HNO from the two perspectives: a) requirements on network maintenance, and b) requirements on qualities of the self-x functionalities.

IV. RESULTS

This section summarizes the result of the analysis of the interviews. Requirements were extracted on two main topics: requirements on network maintenance and on self-x functionalities.

A. Requirements on network maintenance

The requirements the network maintenance sets for HNOs are based on the uncertainty and complexity of network for many reasons: (i) technically (30 notions), a network is affected by many factors that are hard to control (especially complexity due to various types of equipment and the variety of manufacturers). Obsolete, but functional systems create a challenge in themselves as their use prevents the transformation of the network to become more homogeneous and easier to maintain. Furthermore, (ii) a network is never perceived directly but through supervision mechanisms that also may fail or provide insufficient information that cannot be trusted (5 notions). Also, (iii) human work is not always perfect (27 notions): information is not always delivered in time, it may not have been registered in the system that is used in network maintenance, and there might be hurry due to customer needs. Finally, (iv) weather (5 notions) and physical problems (accidental cable cuts and the stealing of cables; 6 notions) cause trouble that are hard to control.

The criterion of the good status of network is clear and strict. Either directly or indirectly (via alarms sent by the supervisory system) the availability and functioning of the network as perceived by the end user or customer service was the most usual way to evaluate the seriousness of a network problem (15 notions, opposed to 6 notions where the operators only referred to their own work). Depending on the Service Level Agreement (SLA), problem must be solved within a certain period.

Network maintenance requires mastering a large set of knowledge related to the various equipment and manufacturers and the ability to react rapidly to network breakdowns, knowing that each breakdown could be solved in a different manner from the previous one. HNOs cannot rely on the information acquired earlier but must update their knowledge constantly in order to be able to maintain the network functional. The demands of acquiring enough information and of maintaining it during rapidly changing situations are hard. The piece of information acquired earlier may be unavailable as the next time it is needed is several months later.

Also cooperation and communication are needed. Network is in a constant change and information of these changes should be constantly updated so that everybody has the essential information available. Additionally, cooperation is an essential part of work for most HNOs; for some, cooperation is required to get help and support when needed (6 notions) and for others, cooperation is part of normal work procedures (11 notions).

B. Requirements on self-x functionalities

The design of the self-x functionality from the perspective of a HNO depends on what the role of this functionality has relative to the tasks that the human operators have on their responsibility. The interviewees, HNOs, did not have a clear vision what the options in this

 ISBN: 978-1-61208-177-9

kind of situation could be, nor were they asked to further elaborate a vision of such a possible future. In many cases, HNOs seemed to describe present functionalities that are automatic instead of elaborating the features of future autonomic functionalities. Some clues can be found from the replies. First, interviewees were aware that self-x functionalities could reduce the amount of personnel needed (22 notions). Second, some opinions were presented according to which the work of the human operator could become easier or that the deployment of self-x results in the possibility for the HNO to do some other, but more productive work (18 notions). Third, self-x could perform better (quicker etc.) than presently (12 notions).

In the following, the general requirements are described, drawn on the information gathered from the interviews.

1) Trust

The trust of the human operator to self-x can be easily destroyed by erroneous functioning of the self-x functionality in question. Possibly, any or only a very few mistakes is sufficient to ruin trust and willingness to use the self-x functionality (16 notions). Furthermore, if the functionality is of the kind that diminishes the need of human personnel, it is probably more intolerable for the rest of personnel to work with such functionality.

The interviewed HNOs stated that demanding tasks – which require human ingenuity as well as solving new and unexpected problems – cannot be performed autonomically (9 notions). The self-x functionalities in this context should work without problems that require human intervention: such problems would probably pose the greatest challenge in network maintenance from the human operator point of view.

Based on the perceived benefits of self-x expressed in the interviews, especially performance speed (7 notions), smaller amount of network breakdowns (3 notions), and stability of performance (10 notions) are characteristics that are valued among HNOs. In addition, the possibility to dedicate routine tasks to self-x functionalities was found an advantage (15 notions). If these qualities can be provided and they function practically without faults, the self-x could be perceived as valuable and needed by HNOs maintaining the network.

2) The need of human control

In the interviews, it was repeatedly stated that the human operator must have some control over the self-x functionalities: the lack of control was perceived as the greatest danger in autonomic functionalities (8 notions). Fault and failure of the autonomic functionality are important to know especially if the HNO needs to act in order to solve the problem. HNOs must also have enough information of the autonomic process so that they can intervene manually in a meaningful way, for instance to perform the task at least partly in lieu of the self-x if needed. If the failure of the self-x causes trouble for network maintenance, amending measures should be easily performable. In general, human control is needed for knowing that the functionalities are working; the urgency to get this status information and the need to control or maintain further the self-x functionalities depends on the nature of the task in question.

3) Interface between HNO and self-x

The performance of self-x functionalities should be visible to the human operator when the self-x performance is somehow connected to the tasks of the human operator. HNOs need information of the functioning of the self-x in a general level. The work of the human operator requires sometimes rapid reactions; it is preferable to deliver clearly and briefly only the most important information, and, when needed, the human operator should be able to find more information about the matter relevant in the context in question.

The interface should include information that enables the evaluation of the performance of the self-x functionality so that it becomes evident whether it is functional or not. If possible, the system should deliver information that supports the HNOs in fixing the problem. In some cases it might even be necessary for the HNO to do manually the work or part of the work that was in the responsibility of the self-x. Last but not least, autonomic system should not overload the human user with recurring information. All in all, opinions of the good interface qualities were scarce and scattered.

4) Designing self-x functionalities

The domain of telecommunication seems to be complex and hard to control. On one hand, operators are somewhat used to the fact that the tools they are using are not perfect at least in the beginning of their deployment. On the other hand, operators should not be burdened by poorly functioning tools as the work is quite straining already and because weaknesses in network maintenance are immediately reflected in the quality of services and customer satisfaction, vital for the telecom companies. Before taking a new functionality into use, it should be thoroughly verified that the functionality works; redesign might be needed later if changes affecting this specific self-x are made in the network.

5) Human tasks

Tasks that are obviously left for humans are all physical tasks: implementing new cables and equipment, organizing cooperation among humans when a cable is cut or equipment must be replaced, and each time something unexpected or totally new is introduced to the network. Some human control must also be maintained to supervise the functioning of the network and of the self-x. What are the tasks that can be totally or mainly relied on self-x functionalities and when and to what extent self-x functionalities may require human involvement are questions that perhaps should be solved by each telecom company, depending on the kind of supervising tools and network equipment they have. Furthermore, the quality of the task determines the party performing the task; for instance, tasks requiring decision making in a highly specific situation without predefined preferences might best be left for humans whereas those requiring rapid and complex functioning that can be performed with existing definitions can be left for autonomic functionalities.

V. DISCUSSION

This paper has presented the methods, analysis, and results of the interviews of HNOs carried out in UniverSelf

 ISBN: 978-1-61208-177-9

project. The interviews have shown that network operators define the network as complex, uncertain, and hard to control. Therefore, specific knowledge is needed to handle the issues that may appear. An autonomic network aiming to be deployed should embed this knowledge in order to success in its self-managed activity.

The analysis has also highlighted that human operators see self-x functionalities as supporting their current work; not necessarily replacing them or performing independently. Even when some of the interviewees expressed their fears about personnel reduction in case autonomic functionalities are deployed into the network, the majority expressed a positive opinion about the introduction of self-x features. In this direction, the HNOs thought that their role might change from current active monitoring and problem solving to an expert performing higher level tasks and solving only highly complex or unexpected problems, while routine tasks are left to the autonomic network. On the other hand, it also became evident that there was no deep understanding of the nature of self-x functionalities among HNOs: The conception of autonomic functionalities was often mixed with the automatic functionalities that are presently used in telecom companies.

The conceptions of human operators on the impact of self-x functionalities – loss of work, division of difficult tasks to autonomic functionalities, and the emerging possibility to do more productive work themselves as autonomic functionalities take over routine tasks – can be translated into a vision in which there are three options for the shared work between HNO and self-x (see Figure 1).

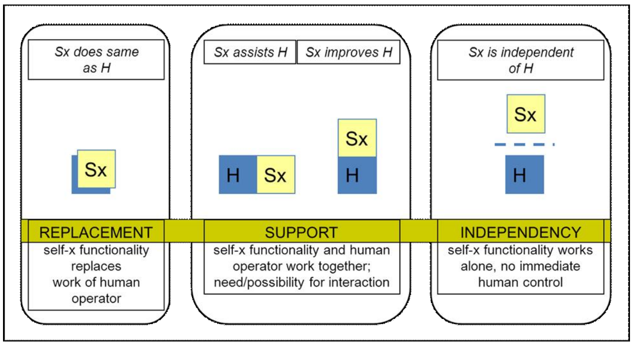

Figure 1. A graph describing the role of self-x functionalities relative to the role of the HNO. Yellow box "Sx" refers to tasks performed by self-x functionalities and blue box "H" refers to tasks performed by HNO. The figure describes three basic alternatives for a share of work between human and technology: Replacement, support and independency.

The conception of losing jobs with the deployment of self-x can be translated into such a solution where self-x functionality replaces human work in some specific task (in Figure 1, the leftmost option, "Replacement"). The option of the self-x functionality to facilitate the work of the HNO is not as easily translatable to a division of work between human and technology. Apparently, self-x functionality then assumes some subtask that the human used to perform or extends it further in some way (e.g., by performing more complex calculations than the human operator is able to do within such a short period of time), supporting the work of the human operator. The functionality may perform part of the work human did earlier or the functionality could do something related to the task human performs but going beyond it for instance in speed or complexity (in Figure 1, the option in the center, "Support", and there the left and right sub options "Sx assists H" and "Sx improves H", respectively).

Interviewees thought they could devote themselves to more productive work while the self-x perform something else, possibly the tedious tasks that require a lot of mechanical work of the human operator but not so much human intellect. Obviously, here it is a question of work that the self-x functionality does entirely or mainly by itself. Basically, this situation develops whenever a self-x functionality takes over any part of human work as it then leaves the human a possibility to do something else, applying both "Replacement" and Support" options.

Additionally, self-x could perform something that human is not able to do but that could either ease the HNO's workload indirectly by, e.g., diminishing the amount of network failures, or elevating the functioning of the network in a totally new way. For this case we invented a third type of solution for the division of the work between the human operator and self-x functionality, labeled here as "Independency" (in Figure 1, the rightmost option). It illustrates the situation where the tasks of human and technology are separate. This option is valid in a situation where the self-x performs something that has never been on the responsibility of a human operator: it could be a new task that enhances or supports network availability or the like, in a new and unique manner.

Human control over the self-x functionalities is needed. If the self-x functionality is used for replacing human work (case "Replacement" in Figure 1) or it assists or improves human performance (case "Support" in Figure 1), it is important to know about the status of the autonomic functionality to guarantee a smooth joint performance between the human and autonomic functioning. More specifically, HNO needs to know if the self-x is functional; due to the nature of work, this should be evident to HNO. HNO also needs to know how to fix a problem in self-x functioning in order to keep the network manageable and functional (provided that the malfunctioning of the self-x functionality causes trouble in these areas). Furthermore, HNO should be able to know how to perform the same or about the same as the self-x functionality in case of failure of the functionality.

However, if the self-x is independent of human work (case "Independency" in Figure 1), the need for human control is not straightforward. An independent task is of the kind that is beyond human capabilities – hence, it can be concluded that when it works as defined, it raises the quality of network functioning but if malfunctioning it might cause trouble and is probably hard to control. Hence, HNO or at least an expert should be able to evaluate whether such functionality is functional but only an expert might have sufficient knowhow to repair a problem in such self-x functionality. There is no possibility for a human to perform the same task manually, anyway.

Making amending measures requires, of course, that self-x functionality has an interface towards the HNO and that the human operator knows enough of the functioning of the self-x so that the information it delivers can be interpreted correctly. Thus, if the malfunctioning of the self-x causes trouble in normal network functioning and/or complicates the work of the human operator, HNO should be able to perceive that there is a problem in the self-x functionality and to infer the severity of it in order to decide whether to intervene or not and if to intervene, how urgently. Furthermore, it should be made possible to conclude what is/are the available way(s) to proceed in problem solving and to have access to means to perform the amending measures.

All the options presented above – replacement, support and independency – don't automatically result in a considerable decrease of personnel. It is possible that in addition to, or instead of decreasing the amount of personnel, self-x functionalities could enable more efficient network maintenance and higher-level services. HNOs could operate alongside self-x or only by human power alone while the more elementary issues are left for the responsibility of self-x. To sum up, the benefits self-x functionalities could bring are not only cost reduction in the form of decreased amount of personnel, but also higher income to the telecom operator due to more sophisticated, more stable, or novel services to customers. What is the relative impact of each of these possibilities remains to be seen.

VI. Conclusion and Future Work

How soon these visions of autonomic networks become true depends on the rate of emergence of self-x functionalities in network maintenance on large scale and on the qualities of the self-x. Possibly some type of joint work arrangement between the human operator and the self-x dominates at first, and the situation evolves with time.

To be effectively useful and widely adopted, the new management system, which also includes the management of self-x functionalities, must provide the telecom operators with tools to seamlessly govern the network infrastructure by means of decision oriented operational tasks rather than low level command execution. At the same time, reliable mechanisms should be included for the human operator to receive all the needed information for the supervision of the network, so that any impossibility to continue self-managed operation or realistic danger will be reported to humans with pertinent details of the situation. Furthermore, tools to start the recovering process are needed as well. The adoption of this approach should decrease the human intervention required for deploying new services and configuring and operating the network.

The results of our interviews have provided a number of requirements about network maintenance and self-x functionalities. Since almost all the knowledge required to manage the current networks resides in the human operators, they may constitute a bottleneck when trying to deploy an autonomic network. The generation of self-x functionalities fulfilling the operator's demands and suggestions will become an important factor for the success of the autonomic networks. The research presented in this document supports the identification and extraction of operator's requirements for this purpose.

Acknowledgment

The research leading to these results has been performed within the UniverSelf project (www.UniverSelf-project.eu) and received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 257513. Additionally, we thank the two telecom companies for giving the permission to perform the interviews and for making the practical arrangements for it; Helena Rivas and Martin Varela for kindly performing the interviews; and last but not least, all the human network operators who shared their opinions and conceptions with us in the interviews.

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 ISBN: 978-1-61208-177-9