A Management Automation Framework for Mobile Networks

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***Abstract*—Future operation, administration, and maintenance (OAM) of mobile networks will be characterized by complex tasks and workflows, whereas requiring a huge amount of human operators causing high operational expenditures (OPEX). Thus, the idea of shifting more and more of these complex tasks from the human operators to the mobile networks and their network elements (NEs) respectively becomes always more important for every mobile network operator (MNO) in order to reduce its OPEX. The final stage of this shifting process may yield completely self-managing mobile networks, an idea and vision originally stemming from the computing industry. However, transferring this idea to mobile networks and achieving it is very complex, as – beneath the general research challenges for such self-managing mobile networks – there exist a couple of domain specific constraints compared to computing systems. Moreover, there also exist certain human challenges, which additionally have to be considered, as they complicate the successful integration of management automation technologies and solutions for mobile networks evermore.**

Thus, immense efforts are spent by the telecommunication industry within research communities, initiatives, and forums in any directions to converge to this vision, which result in a widely scattered landscape of management automation technologies and solutions. This paper therefore aims to provide a management automation framework that, on the one hand, allows the classification of any management automation technologies or solutions as well as enables the identification of their contribution to the overall vision, and on the other hand, shows a strategic way to cope with the human challenges constraining their operational integration.

***Index Terms*—Management automation, OAM, OPEX reduction, self-management.**

I. INTRODUCTION

Since the very beginning of mobile communication, operation, administration, and maintenance (OAM) of an underlying mobile network is a crucial task to every mobile network operator (MNO). To this day, human operators mainly accomplish the tasks and workflows for OAM manually, while only few tasks have been automated so far, mainly for network monitoring. However, MNOs and their human operators respectively are faced a couple of challenges in future: They will have to cope with more distributed and decentralized network architectures with large numbers of specialized network elements (NEs), more frequent (re)-configurations of NEs due to moving and dynamic networks, as well as a higher diversity due to heterogeneous NEs. Additionally, there will be always shorter product cycles, a tighter time to market and after all a broader feature offer. Thus, the increasing NE/network complexity and diversity will require more complex and specialized management solutions while at the same time the increasing network size and dynamics will require a faster processing of more management data and tasks. An ongoing manual processing of OAM tasks and workflows for such natured future mobile networks would be very labor intensive and thus cause high hourly costs, i.e. the operational expenditures (OPEX) of MNOs would permanently increase.

Thus, it will be crucial for all MNOs to automate more and more OAM tasks and workflows, i.e. shifting them from the human operators to the mobile networks and their NEs respectively. This shifting may start with the transfer of low-leveled NE management tasks, might go on with the transfer of element management tasks, as well as later even network management tasks. Finally, the highest level of management automation would consequently yield a self-managing mobile network. At this stage, the burden of management would rest on a mobile network itself while human operators would only have to provide high-level guidance, e.g. by policies, to OAM.

This idea and vision originally stems from the computing industry, which is faced with comparable conditions. However, transferring and achieving this vision to mobile networks is not easy, as there exist a couple of domain specific constraints and challenges compared to computing systems, e.g. the scalability of the underlying network or the bandwidth per NE. Moreover, there also exist – beneath the general research challenges for such self-managing mobile networks – certain human challenges, which additionally have to be considered, as they complicate the successful integration of management automation technologies or solutions for mobile networks evermore.

To converge consequently to this vision, immense efforts are spent by the telecommunication industry, either within initiatives and forums (e.g. see Autonomic Communication Forum [1], TeleManagement Forum [2], Celtic Initiative [3], Wireless World Research Forum [4], [5], or Next Generation Mobile Networks [6]), manufacturers (e.g. [7]-[9]), or other research projects (e.g. see [10]-[12]). The management automation results of all of these activities produce a widely scattered landscape of management automation technologies and solutions, with a diverse contribution grade to the final vision.

This paper therefore aims to provide a management automation framework that, on the one hand, allows the classification of any management automation technologies and solutions as well as enables the identification of their contribution to the overall vision, and on the other hand, shows a strategic way to cope with the human challenges constraining their operational integration.

Thus, the rest of this paper is structured as follows. Section II presents the vision of self-managing mobile networks along with a description of the properties that make up this highest level of management automation. After that, section III lists the challenges grouped by general research challenges, domain specific challenges, and human challenges that have to be considered for future research as well as for the successful integration of new management automation technologies. In section IV, the management automation framework is presented, whereas section V concludes this paper.

II. VISION OF SELF-MANAGING MOBILE NETWORKS

In order to get a picture of the self-management vision as well as to understand, why self-management it is the highest level of management automation, one has to know about the origin of the term self-management and its primary concepts. After that the description of a self-managing mobile network is given.

A. The origin of the idea

In 1965, Gordon Moore observed that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented. Moore also predicted that this trend would continue for the near future. In subsequent years, the pace slowed down a bit, but data density has doubled approximately every 18 months, and this is the current definition of Moore's Law, which Moore himself has blessed. Most experts, including Moore himself, expect Moore's Law to hold for at least another one to two decades. Due to this fact, always more complex and efficient applications, systems, and networks were designed, which require a huge number of human administrators for their configuration, their adjustment, and their maintenance – in short: their management. This in turn permanently increased the OPEX of enterprises using such complex computing systems.

In 2001, more then 30 years after Moore’s prediction, this fact caused IBM, to postulate a change in the design of computing systems [13]. According to this vision, future computing systems should be based on the idea of the human autonomous nervous system (ANS). The ANS controls such low-level but vital tasks as breathing, pulsing, or sweating without the conscious control of the human brain, which is thus freed for other important tasks. Based on this paradigm, IBM proposed several properties future self-managing computing systems are expected to possess analog to the ANS and in order to remain manageable: they should be (amongst others) self-configuring, self-optimizing, self-healing, and self-protecting, commonly referred to as self-* properties. Thus, the control of self-managing computing systems by human administrators will no more take place on lower levels in terms of specific commands, but on more abstract and higher levels in terms of management objectives.

However, self-management is not a radical new idea or technology by itself. Automating the management of computing resources is a well-known problem for computer scientists. For decades, system components and software have been evolving to deal with the increased complexity of system control, resource sharing, and operational management. Self-management is just the next logical evolution of these past trends to address the increasingly complex and distributed computing environments of today [14]. The composition of several self-managed subcomponents brings the value added to companies.

B. Primary concepts

To combine research efforts in this area and to reach the self-management vision, IBM announced the Autonomic Computing Initiative (ACI) [15]. Short after IBM, a couple of other IT vendors also have recognized the management complexity of computing systems and started several initiatives with mainly the same intentions, e.g. Microsoft (Dynamic Systems Initiative [16]), HP (Adaptive Enterprise [17]), Sun (N1 [18]), or Hitachi (Harmonious Computing [19]). Despite all these activities, the primary concepts for self-managing autonomic computing systems were proposed by the ACI. Although the ACI does not address self-managing mobile networks in the first instance, it provides general concepts that may be used for the later self-management of mobile networks too.

The reference architecture for autonomic computing systems [20] is based on the first architectural approach for these systems [21] and is composed of five layers: the first and lowest layer contains the system components, or managed resources (MR), that make up the IT infrastructure of a company. These MRs can be any type of resource (HW/SW components as servers, databases, or business applications) and may have embedded self-managing attributes. So-called touchpoints on the next level provide a manageability interface for each MR – similar to an API – by mapping standard sensor and effector interfaces on the sensor and effector mechanisms (e.g. commands, configuration files, events, or log files) of a specific MR. Layers three and four automate some portion of the IT process using an autonomic manager (AM). A particular MR may have one or more touchpoint autonomic managers, each implementing a relevant control loop. Layer four contains autonomic managers that orchestrate other autonomic managers. These orchestrating autonomic managers deliver a system wide autonomic capability by incorporating control loops that have the broadest view of the overall IT infrastructure. An AM and all it’s MRs (that can be AMs again) are combined to an autonomic element (AE). The fifth and top layer illustrates a manual manager that provides a common system management interface for the human administrators using an integrated solutions console. All five layers together build up an autonomic computing system.

The AM within an AE generally implements an intelligent control loop (closed feedback loop) called MAPE loop (see Fig. 1). The latter is composed of the components monitor (collects, aggregates, filters and reports MR’s details), analyze (correlates and models complex situations), plan (constructs actions needed to achieve goals) and execute (controls execution of a plan). Additionally, a knowledge component provides the data used by the four components, including policies, historical logs, and metrics.

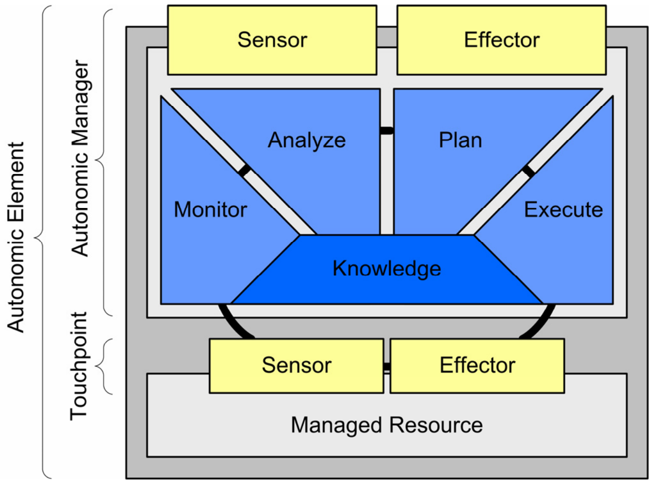

Fig. 1: An autonomic element according to the AC reference architecture

C. *Self-* properties of mobile networks*

Due to the very similar conditions regarding complexity in mobile networks (as described in section I), the transfer of this self-management idea becomes always more important for the telecommunication industry. Similar to self-managing computing systems, a self-managing mobile network thus can be defined as a mobile network exposing self-* properties. However, in mobile networks, these self-* properties have a slightly different meaning compared to computing systems:

Self-configuration: Self-configuring NEs adapt dynamically to changes in the network environment, using policies provided by the human operators. Such changes could include the adding of new NEs, the removal or re-homing of existing NEs, or dramatic changes in the network characteristics. Such a dynamic adaptation helps to ensure the continuous availability of the entire mobile network.

Self-optimization: Self-optimizing NEs can tune themselves to meet user or MNO needs. The tuning actions could mean reallocating bandwidth – such as in response to dynamically changing workloads – to improve overall utilization, or ensuring that particular data transfers can be completed in a timely fashion according to defined QoSs.

Self-healing: Self-healing NEs can detect system malfunctions and initiate policy-based corrective actions without disrupting a sub-network for instance. Corrective actions could involve software altering its own state or effecting changes in other NE in the environment. The mobile network as a whole becomes more resilient because day-to-day operations are less likely to fail.

Self-protection: Self-protecting NEs can detect hostile behaviors as they occur and take corrective actions to make themselves less vulnerable. The hostile behaviors can include unauthorized network access and use, virus infection, and proliferation. Self-protecting capabilities allow MNOs to enforce consistently security and privacy policies.

III. CHALLENGES

In order to setup a framework for management automation technologies and solutions, diverse challenges to be mastered on the way to self-managing mobile networks have to be considered. These challenges are divided into three parts: general research challenges, mobile network specific challenges, and human challenges. The general research challenges will influence the classification schema, whereas the mobile network specific challenges are the domain constraints for those challenges that have to be considered for research in the same ways as the human challenges responsible for a successful integration of all approaches.

A. *General research challenges*

General research challenges are applicable to every kind of self-managing systems, either computing systems, mobile networks, or any other systems. In [22] a framework for such general research challenges – the research challenges of autonomic computing – is described that proved to be useful in defining and describing IBM's autonomic computing research program. These research challenges are taken as a basis for the research challenges for self-managing mobile networks. Table 1 summarizes and illustrates this adjustment.

At the very coarsest level, the research challenges are divided into three basic areas: research on self-managing network elements, self-managing mobile networks, and human-computer-interactions. Every research area then is divided into two or three sub-branches again that specify the challenges in some more detail.

B. *Mobile network specific challenges*

Beneath these general research challenges, the particular characteristics of mobile networks result in some additional domain specific challenges and represent the constraints that have to be considered for research. These challenges often are responsible for the non-applicability of certain management automation techniques for computing systems on mobile networks.

Encapsulation of legacy system architectures: As future mobile network architectures, e.g. 3G LTE/SAE or B3G, will have to encapsulate legacy system architectures for a long time, these architectures have to be considered for management automation too. This means that management automation techniques cannot be design regarding future mobile networks or NEs only, but have to consider legacy NEs that may not have required self-management functionalities.

Closed feedback loops: As described in the previous section, full autonomic systems require the introduction of closed feedback loops between managers and managed resources. In mobile networks, such entities often are vendor-specific, what would require uniform management interfaces (touchpoints) between the managed resources and managers, as well as between different managers.

Scalability: The focus of self-managing systems in the computing industry is on solutions of management problems of huge computing systems in companies. Thus, the scalability (management scope) is at most up to some hundreds of managed resources. In mobile networks, the management scope is however up to some thousands of NEs, which makes the control much more difficult.

Infrastructure: The infrastructure of a mobile network differs in a couple of aspects from the infrastructure in computing networks. While in computing networks the connections between the computers are cheap in terms of bandwidth, in mobile networks bandwidth may be an expensive resource for equipment in remote location. Thus, the management traffic on this resource has to be reduced on a minimum in mobile networks. Furthermore, in computing systems, storage capacity and computing power of managed resources are much higher as in the NEs.

Architecture: The autonomic computing reference architecture provides and hierarchical approach for autonomic computing systems. However, the evolution of future mobile network architectures tends to more distributed and flat (management) architectures, what may require more horizontal management concepts instead of vertical concepts as in computing systems.

TABLE 1: GENERAL RESEARCH CHALLENGES APPLIED TO MOBILE NETWORKS

Research area	*Research sub-branch*	*Description*
Research on human-computer-interaction	Policies	Higher-level forms of policies based on goals and utility functions that enable a high-level guidance by human operators
	Human studies	Developing new languages and metaphors that will enable human operators to monitor, visualize, and control self-managing mobile networks
Research on self-managing mobile networks	Self-managing mobile network science	Control and exploitation of emergent behavior and potential uses of economic mechanisms (auctions, bilateral negotiation, …)
	Self-managing mobile network management architectures and prototypes	Common behaviors, interfaces and interaction patterns that are demonstrably capable of engendering system-level self-management
	Self-managing mobile network technology	Technologies associated with system-level self-configuration, self-healing, self-optimization, and self-protection
Research on self-managing network elements	Generic self-managing network element architectures, tools, and prototypes	Creating a single self-managing network element that functions competently in a self-managing mobile network / toolkit development
	Generic self-managing network element technology	Technologies for monitoring, event correlation, rule execution, modeling, optimization, forecasting, planning, feedback control, and machine learning
	Specific self-managing network elements	Making individual network element components (databases, cards, …) more self-managing

A. *Human challenges*

In addition to the upper challenges, a few more, important challenges regarding the human operators come along with the integration of self-management approaches at MNO sites. Of course, some of them may be valid in other domains too:

Knowledge acquisition: Today, most of the (critical) domain knowledge for OAM is held by the human operators. However, in order to design self-managing solutions, this domain knowledge is required. Ways have to be found to acquire and capture all this knowledge while not starting from scratch again.

Operator acceptance: One of the most difficult challenges is the acceptance of management automation technologies/solutions and autonomous actions of self-managing mobile networks by human operators. The reason is that management automation solutions are commonly considered as job killers rather than job shifters from lower-level to higher-level management tasks, e.g. management policy design. This challenge intensifies the knowledge acquisition challenge anymore.

Ensuring of operator control: The autonomous actions of a self-managing mobile network must be transparently and controllable. The human operators providing the management objectives must have confidence in the self-managing network and have to be kept informed about the made decisions by the system. They have to have the possibility to intervene at any state of the system.

Liability: In order help operators to trust a self-managing mobile network, certain guarantees on the behavior of the autonomous system have to be delivered by hardware and software vendors, especially when the solutions are based on concepts as self-organization or emergence.

IV. MANAGEMENT AUTOMATION FRAMEWORK

As already mentioned, the proposed management automation framework has the following purposes:

- Enabling the classification of any management automation technologies or solutions helping to achieve self-managing mobile networks

- Enabling the identification of the contribution of a management automation technology to this vision
- Showing a strategic way for coping with the human challenges constraining the operational integration of (new) management automation technologies and solutions

Therefore, the management automation framework is built up on two models, the Telecommunications Management Network (TMN) model, stemming from the telecommunications area, and the Autonomic Computing adoption model [20], stemming from the IT area.

The AC adoption model originally was developed by IBM in order to provide a methodology for IT-businesses to calibrate the degree of autonomic capability that their current infrastructure has, and to develop action plans to increase its autonomic potential. These objectives make the model suitable for the adjustment for the management automation framework. The original model provides an autonomic capability matrix originally comprising a "functionality" dimension, a "scope" dimension, and a "service workflow" dimension. For the management automation framework the AC adoption model is mapped on the five-layered TMN with certain adjustments, which results in a three-dimensional management cube representing the management automation framework (see Fig. 2).

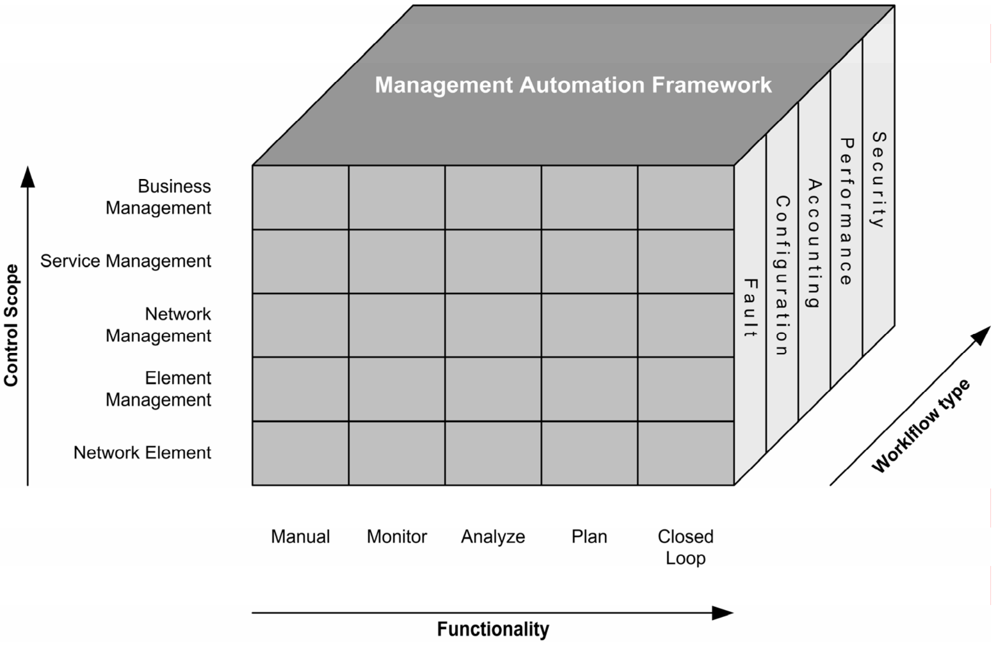

Fig. 2: Management automation framework for mobile networks

A. *Functionality dimension*

The functionality dimension, along the x-axis of the management automation framework, characterizes the extent of automation of a management task, process, or workflow. Five levels of automation are defined:

Manual level: All parameters of every control scope layer (network element layer, element management layer, network management layer, service management layer, and business management layer) are changed and adjusted manually by human operators. Every management process and task has to be initiated and executed by human operators while the network itself has no intelligence at all. Management automation only takes places by proprietary scripts that may be selected by the operators. This management level hence evokes the highest OPEX for a MNO and represents the *basic level* of autonomic maturity.

Monitor level: Management technologies can be used to collect detailed data from the network, helping to reduce the time it takes human operators to collect, aggregate, and link information from one or multiple NEs, or to recognize symptoms. This management level in particular will reduce OPEX as the NEs within a network increase and the network becomes more complex, and hence represents the *managed level* of autonomic maturity.

Analysis level: New technologies are introduced to provide correlation among several NEs. The management functions can begin to preprocess data, correlate symptoms, and recognize patterns. An OPEX reduction is achieved mainly by a useful data reduction. The planning and execution of necessary actions remain in the hand of the operators. This management level represents the *predictive level* of autonomic maturity.

Plan level: The plan level is not part of the AC adoption model, but it was introduced in the management automation framework to reduce the gap between the prior (analysis) and the next level (closed loop). At the plan level, the management functions predict the optimal configuration, and offer advice about what course of action the operator should take. However, the decision of what action will be taken in reality remains to the operators. This management level hence represents the *adaptive level* of autonomic maturity. OPEX are reduced by the time it takes the operators to plan appropriate configurations and actions.

Closed loop level: The network and its elements can automatically take actions based on the available information and the knowledge about what is happening in the environment, while policies and objectives govern the network OAM. Operators interact with the autonomic technology tools to monitor the processes, alter the objectives or both. This management automation level represents the highest *(autonomic) level* of autonomic maturity. Hence, it will yield the highest OPEX reduction as it reduces the time and effort spent by human operators for OAM at most. (The AC adoption model has one more level, named closed loop with business processes, but this is not useful here.)

Comparing these five levels of the functionality dimension with the concepts of a MAPE loop of the AC reference architecture (see subsection II.B), it becomes evident that in every level an additional logical component of the MAPE loop is added. While at the manual level, every function has to be processed manually by human operators, at the control loop level all these functions are processed by the management system itself.

B. Control scope dimension

The control scope dimension, along the y-axis, characterizes the layers on that management takes place. These layers are congruent to the TMN management layers and range from the Network Element layer to the Business Management layer:

At the *Network Element layer*, the management activities stretch across the components of a NE, such as the operating system, the firmware, other software, or a card.

At the *Element Management layer*, one or more NEs (subnetwork) are managed, such as NodeBs or a RNCs.

At the *Network Management layer*, not only a couple of subnetworks are managed, but the complete mobile network. This means that the management from the upper layers' point of view is not vendor-specific but vendor independent.

At the *Service Management layer*, the management activities include functions for the handling of services in the network.

At the *Business Management layer*, the management activities include functions related to business aspects, analyze trends and quality issues, for example, or provide a basis for billing and other financial reports.

C. Workflow type dimension

The workflow type dimension, along the z-axis, captures the combination of OAM functional areas, i.e. for Configuration Management (CM), Performance Management (PM), Fault Management (FM), Security Management (SM), and Accounting, which are being performed. Various OAM functional areas might demonstrate different maturity levels (in terms of automation functionality and control scope) at the same time, as various tasks and activities within particular workflows are automated. However, within one particular functional area there may be differences between the maturity of certain workflows, e.g. the workflow for adding a new NE might be more automated as the workflow for re-homing a NE, although both workflows are part of the CM functional area. Hence, every functional area additionally can be partitioned into functional subareas.

D. Semantics of the framework

By the addition of a third dimension to the TMN, the extent of management automation technologies or solutions becomes measurable. For example, the classification of a specific management automation solution into the matrix entry on the "closed loop" level of the "Network Element" layer and the "PM" area indicate, that this solution enables the self-optimization of a NE. All other entries of the same layer and for the same workflow type represent a certain degree of maturity of a management automation solution, which may contribute to self-optimization, but does not enable it on its own.

For example, let us look at management automation solutions for a management task like "traffic balancing" on a NE. As those solutions improve the performance of NEs, they are classified into the PM area of the "workflow type" dimension.

Let us assume a specific solution "A" is primarily intended for a single NE, then it is classified into the "Element Management layer" of the "control scope" dimension. If all tasks for traffic balancing of solution "A" are performed manually, then this solution would be classified into the first level ("manual") of the "functionality" dimension. This classification shows that there is no contribution of the solution "A" to the vision of self-optimizing NEs, as all required tasks are performed by human operators manually.

Let us assume there is a second management automation solution "B" that already collects data of a NE and preprocesses them in a log file. This means, there exists already an automatic monitoring of traffic data and hence solution "B" would be classified into the second level ("monitor") of the "functionality" dimension, indicating that "B" contributes more to the convergence to the self-optimization vision than "A".

Let us now assume, there is a solution "C" that uses key performance indicators (KPI) on a NE and sends an alarm if the traffic on this NE exceeds a certain threshold. This means, that the NE is already able to analyze collected data, which classifies the solution "C" into the third level ("analyze") of the "functionality" dimension, indicating its higher contribution to self-optimization.

Now, let us assume, there is a solution "D" that applies the solution "C" to a group of NEs within a subnetwork. This solution does not improve the functionality of a network element, but the control scope of the network. Hence, the solution "D" would be still classified into the third level on the "functionality" dimension, but now also into the third level ("Network Management layer") of the "control scope" dimension, and thus contribute to the self-optimization vision of mobile networks.

If there would be a solution "E", that uses solution "D" not only for traffic balancing between NEs, but also for traffic backhauling in cases of failures on NEs, then solution "E" would be also classified into the FM area of the "workflow type" dimension.

This little example demonstrates that there exist three ways of contributing to the vision of self-managing mobile networks:

- Automating more functions as the functionality level increases (functionality dimension)
- Applying automated functions to broader resource scopes (control scope dimension)
- Automating a range of tasks and activities for various OAM functional areas (workflow type dimension)

V. CONCLUSIONS

Due to the three dimensions of the management automation framework, which emerged from the mapping and adjustment of the TMN model and the AC adoption model, any management automation technology or solution now can be classified and evaluated.

This third dimension also enables the guidance of human operators to the vision of self-managing mobile networks. In order to cope with the operator acceptance of new management automation technologies and solutions, it is important to integrate these solutions only stepwise. Every step should demonstrate the value added of this solution. As these technologies and solutions on a certain level improve and as operators become more comfortable with them, the solutions can progress to the next level and finally converge to the “closed loop” level. By the classification of a management automation solution it can be determined, if this classification level is already reached and improved by integrated solutions. If so and if the operators are familiar with this level and clearly see the value added, then this new solution can be integrated. For example, integrating a self-organized and completely autonomic solution on the network management layer would be not accepted by the operators today, as this grade of autonomy would skip certain steps.

Note, the management automation framework allows no assumption on the completeness of a certain matrix entry. In particular, it is not possible to determine, when a management automation stage is completely achieved. This issue always depends on the specific requirements of the management automation needed.

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