Standardization of an Autonomicity-Enabled Mesh Architecture Framework, from ETSI-AFI Group perspective: Work in Progress (Part 2 of 2)

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Abstract— **In this two-part paper we describe the ongoing standardization work on designing an autonomicity-enabled mesh architecture framework. This is work in progress being carried out by the AFI (Autonomic network engineering for the self-managing Future Internet) working group of the European Telecommunications Standards Institute (ETSI). In the first part (a separate paper), we briefly described the AFI GANA (Generic Autonomic Network Architecture) Reference Model for autonomic network engineering, cognition and self-management, and discussed general instantiation issues. In this second part we describe the steps needed to accomplish an instantiation of GANA onto wireless mesh networks—thereby creating an autonomicity-enabled wireless mesh architecture. Additionally, we present an example use case showcasing autonomic cooperative networking.**

Index Terms— **autonomic network architecture, European Telecommunications Standards Institute (ETSI), self-management, wireless mesh networks.**

I. Introduction

This paper comprises the second part of the description of the standardization work conducted within Work Item (WI) #3 by the AFI (Autonomic network engineering for the self-managing Future Internet) working group of the European Telecommunications Standards Institute (ETSI). The goal is enabling standardized network architectures with autonomicity. This is accomplished by properly instantiating the AFI GANA (Generic Autonomic Network Architecture) Reference Model onto these designated architectures. Whereas the first part [1] of this work focused on the description of generic instantiation issues, this paper details the instantiation onto a specific network architecture. Specifically, this paper aims to demonstrate the process of instantiating the Functional Blocks (FBs) and Reference Points (Rfps) of the AFI GANA Model onto an IEEE 802.11 compliant wireless mesh network architecture, thus transforming the latter into a *holistic autonomic wireless mesh architecture*.

IEEE 802.11 compliant wireless mesh networks are based on a dynamically created relaying network composed of several wireless stationary nodes, so as to provide Internet access to the users, when and where the traditional way (fixed access networks or access networks based on a single wireless access point) is deemed technically inadequate or inexpedient. For instance, this might cover cases where the estimated time of deployment seems to be relatively long or the investment is planned to be strictly temporary (e.g., providing Internet access during sport events). Moreover, wireless mesh networks provide an excellent example architecture for demonstrating the GANA instantiation process boosted by (a) the availability of commercial-off-the-shelf devices with plug & play capabilities, (b) the existence of functionalities that offer the opportunities to introduce autonomicity such as self awareness (neighborhood discovery), self-configuration (peer establishment), self-optimization (channel management), etc. ,and also by (c) the fact that such networks already embed by design some self-* capabilities.

The instantiation process is expected to present to the mesh networking community an "Autonomicity-Enabled Mesh Architecture Framework", i.e., a framework that will help/guide designers of control-loops to identify where to place the control-loops and cognition functions (by taking into account the notion of nesting and hierarchy of control-loops, slow and fast control-loops) and how to instantiate the Knowledge Plane (KP), the governance mechanism and the associated Rfps in wireless mesh networks. In the opposite direction, by adopting and applying this framework from AFI,

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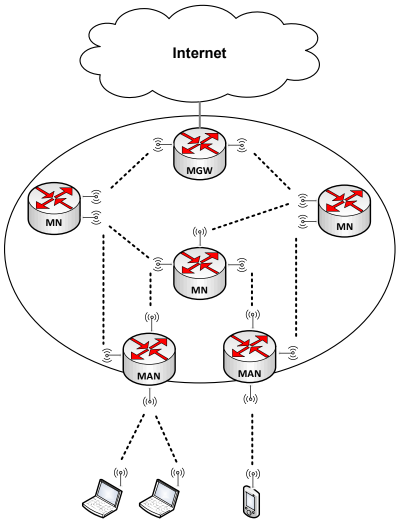

Fig. 1 Typical mesh network

the mesh networking community can help contribute to a further description of the characteristics of the instantiated FBs and Rfps by using accumulated experience from other architectural frameworks, projects and results from industry indicating a successful implementation. The mesh networking community can map their own work onto this particular autonomicity-enabled mesh network architecture in order to elaborate more on implementation-oriented details, e.g., by indicating the candidate protocols that can be used to convey characteristic information exchanged on a particular Rfp.

The rest of the paper is organized as follows. Section II gives an overview of the characteristics of the assumptions for the wireless mesh networks that we envisage in this mapping exercise. The steps needed for accomplishing an instantiation of GANA onto wireless mesh networks are described in Sections III to VII. Finally, Section VIII concludes the paper.

II. Background on Mesh Networks

A typical mesh network consists of several mesh nodes equipped with wireless interfaces providing network connectivity from access nodes through the gateway to the core network. The whole mesh network is typically operated by a single provider offering a relaying service for other providers or simply regular Internet access to end-users. The mesh network topology can be dynamically established and dynamically reconfigured by enabling or disabling particular links between nodes. The most important feature of the mesh network is its extendability, but in order to fully benefit from this, autonomic system design principles, such as disseminating local knowledge and self-organizing mechanisms, are required to be implemented within the mesh protocol stack.

The most typical wireless mesh network topology is depicted in Fig. 1. It consists of interconnected generic mesh nodes. Each node is equipped with at least one wireless interface and can belong to one of three types. The Mesh Gateway (MGW) is a node connecting the mesh network to the

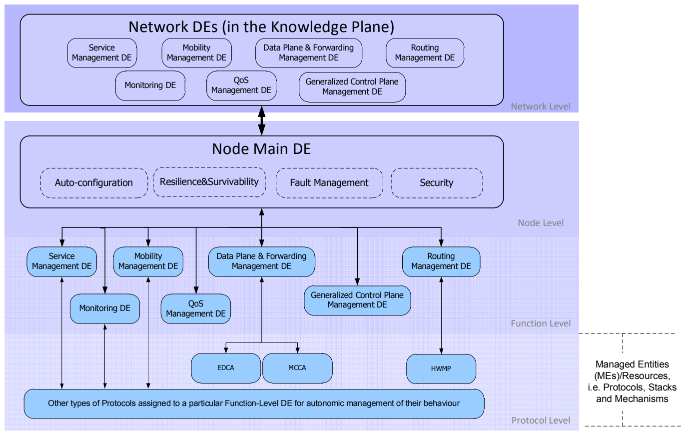

Fig. 2 Block diagram of Decision Elements in autonomicity-enabled mesh architecture

Internet. The Mesh Access Node (MAN) offers network access service to end users. MANs are typically equipped with at least two wireless interfaces: one responsible for providing the network access service and the other responsible for mesh network connection. Finally, the Mesh Node (MN) is a node interconnecting MANs with MGWs, responsible for relaying user traffic.

Mesh networks differ considerably from the typical ad-hoc or infrastructure operational modes of IEEE 802.11 networks. The most fundamental differences are as follows:

- Nodes are stationary, so routing protocols do not need to take into account mobility aspects.
- Nodes have regular power-supply, so power-saving issues need not be analyzed.
- All traffic in the wireless mesh is transit: it is relayed from MANs towards the MGWs.
- The relaying MN has a limited set of links to its neighboring nodes.

The characteristics mentioned above lead to the conclusion, that a simple adaptation and direct implementation of well-known solutions, e.g., fixed or mobile routing protocols from ad-hoc networks, may result in non-optimal network operation.

The commercial success of wireless mesh network deployment may only be possible if the following goals are achieved:

- connectivity with an adequate quality of service,
- the ability to perform dynamic node reconfiguration caused by the degradation of propagation conditions,
- smooth initial deployment and autoconfiguration of new nodes connecting to an existing mesh network,
- node design as an open platform to be easily extended with new radio technologies.

From this perspective it is clear that self-organizing mechanisms are essential for wireless mesh networks.

III. Instantiation of Functional Blocks

The GANA reference model defines a framework and a structure facilitating the specification and design of the relevant FBs, which are specific to realize autonomicity, cognition, and self-management. Individual FBs could be seen as functional elements, or architectural components, performing certain functions. When talking about standardizable "autonomic behaviors" we refer to the fundamental behaviors of the Functional Blocks for autonomicity and self-management during the process of, e.g., self-awareness and self-configuration of network elements in a plug and play fashion. This includes how the Decision Elements (DEs) discover network entities and network objectives/goals, profiles, policies, and data which they require for the configuration of the network elements and the network as a whole.

The GANA Reference Model is abstract and it is described in a technology independent way. Fig. 2 illustrates its instantiation onto mesh networks including the definition of the FBs for the abovementioned and other processes, as well as their interconnections between particular DE hierarchy levels. Specific mesh functionalities of selected DEs at the function, node and network GANA levels are presented in Table I.

There are four characteristic mesh DEs defined at the GANA Function-Level: Monitoring, Data Plane & Forwarding Management, Generalized Control Plane Management, And Routing Management. The Monitoring DE is responsible for providing cross-layer measurements to support other DEs, also those which are defined at other GANA levels. The Data Plane & Forwarding Management DE manages the medium access function (e.g., EDCA) at the GANA Protocol-Level. It also addresses node synchronization and coordination issues. The main function of the Generalized Control Plane Management DE is to optimize the mesh network (e.g., provide efficient transmission of management frames, power control, and channel management). Finally, the Routing Management DE configures and manages the routing protocols (several of them can coexist in one mesh network) for each wireless interface located in every mesh node.

The Autoconfiguration DE is one of the most important Node-Level DEs for a mesh network. It realizes a number of management functions such as addressing, channel management, neighborhood discovery, peer establishment, and topology management. These functions can also support other self-management methods.

Four more DEs which are very specific for mesh networks are defined at the GANA Network-Level. The Monitoring DE stores measurements and applies analysis and reasoning using cognition functions over much longer time periods (hours, days or weeks) compared to the measurements performed at the GANA Function-Level. This allows to introduce and calculate new parameters such as link stability, which can help routing protocols avoid using unstable mesh links. The Data Plane & Forwarding Management DE requires global knowledge about the network behavior to realize its control loop (to avoid instability this should be executed much slower). Finally, the Generalized Control Plane Management DE manages control plane protocols along with the Routing Management DE which optimizes the mesh network routing taking into account a number of variables such as number of hops, flow capacities, node addresses, ciphering, and channel planning.

TABLE I
SPECIFIC MESH FUNCTIONALITIES OF SELECTED DEs

GANA Level	DE	Specific mesh functionality
Function	Monitoring	Configures and manages passive and active measurements. Provides cross-layer measurements to support other functions.
Function	Data Plane & Forwarding Management	Manages the medium access function and node coordination.
Function	Generalized Control Plane Management	Manages beaconing for synchronization purposes, performs power control to optimize the energy consumption and interferences level and channel management for performance optimization.
Function	Routing Management	Manages the routing protocol (proactive/reactive/hybrid) on each mesh node interface.
Node	Autoconfiguration	Manages neighborhood discovery, secure peer establishment, addressing, channel management, topology management.
Network	Monitoring	Analyzes/learns/reasons on long term data measurements (e.g., link stability for correct routing decisions)
Network	Data Plane & Forwarding Management	Realizes slower control loop, when wider global knowledge is required in addressing the problems affecting the forwarding behavior.
Network	Generalized Control Plane Management	Manages control plane protocols and mechanisms
Network	Routing Management	Optimizes flow capacity, number of hops, link reliability, provides network-wide address, topology, channel management.

IV. INSTANTIATION OF THE KNOWLEDGE PLANE

The Knowledge Plane (KP), regardless of the network infrastructure type, is a pervasive system within the network that builds and maintains high-level models for the network operation in order to provide services and advice to other elements/domains of the network, e.g., learning schemes. The GANA KP consists of the Network-Level-DEs, the Model-Based-Translation Service (MBTS) and the Overlay Network for Information eXchange (ONIX) [2]. MBTS forms an intermediation layer between the KP and the network elements. The MBTS translates commands and responses between the Network-Level-DEs and a target command syntax and semantic formulation acceptable to the type of a target node/device. ONIX is a distributed scalable system of information servers that form an overlay network for information/knowledge acquisition and sharing (i.e., publish/subscribe, query/search mechanisms that must be supported by information/knowledge storage repositories). The capabilities of network elements, profiles, goals, and policies of the autonomic network are characteristic examples of information/knowledge that the KP exchanges with the other

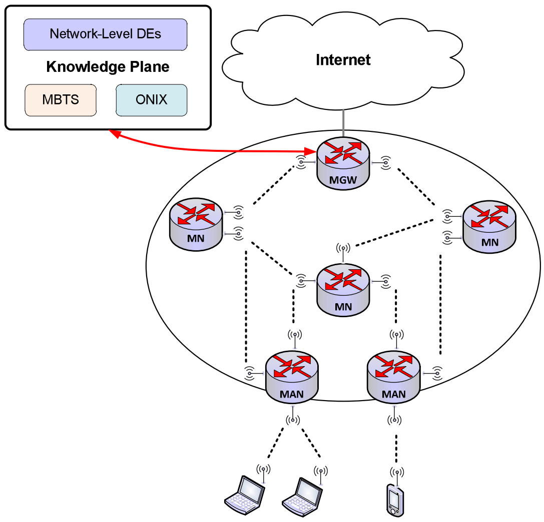

Fig. 3 Centralized Knowledge Plane in a mesh network

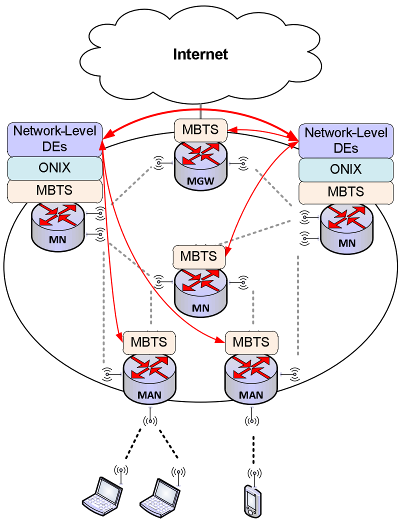

Fig. 4 Overlay Knowledge Plane in a mesh network

GANA DEs.

In the literature there are various scenarios and business cases for the deployment and the maintenance of mesh networks. In each case different requirements and constraints arise in terms of delay, trust, performance, security, etc., according to the purpose for the formation of the mesh network, hence affecting the deployment strategy for the KP. Two paradigms have been identified for the instantiation of the KP to mesh networks, namely centralized and overlay [3].

A *centralized KP* is instantiated as a separate functional block that is placed outside the mesh network area (Fig. 3). This functional block has a global view of the network, coordinating its functions. It is owned and controlled by a specific actor, e.g., network operator. The KP is hosted in a predefined position. The discovery phase is mainly driven by the MGW which keeps the KP address, and provides it to other nodes upon request. In addition, the MGW provides the KP address to a newly deployed mesh node after it joins the network.

An *overlay KP* is deployed in a distributed manner inside the mesh network nodes (Fig. 4). This type of KP is selected

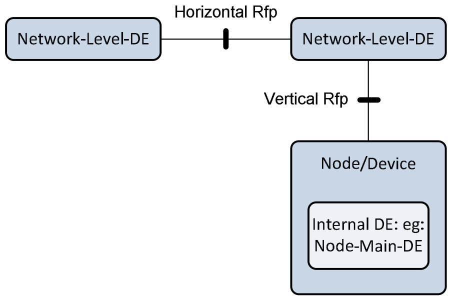

Fig. 5 Example of Reference Points on vertical and horizontal interfaces

for the case where a separate/standalone KP is not available or accessible. This overlay KP analyses the behaviors of the network and collaboratively provides nodes with knowledge to control the network with the same goal, e.g., optimization. An overlay KP can be defined as a medium-term (or in some occasions opportunistic) federation of mesh nodes for the instantiation of the KP blocks (i.e., GANA Network-Level-DEs, MBTS). These blocks are not placed in a single mesh node. Two major challenges arise for the overlay KP: a) the creation and the allocation of the KP blocks in the mesh network, and b) the KP discovery by nodes. The type of mesh nodes or even the expected lifetime of the mesh network are some of the criteria that could drive the instantiation of the overlay and the GANA Network-Level-DEs that meet the goals set by the governance. The overlay topology is established using a clustering scheme that partitions the mesh topology, electing head nodes and simple members. The head nodes host the necessary GANA Network-Level-DEs, thereby emulating the abstract network level. In this case, apart from the KP interfaces that have been described in WI#2, a KP-2-KP interface is required for the collaborations among the heads of the identified clusters. The MBTS block is placed per mesh node, since various types of nodes might constitute the mesh topology with specific data models.

In both deployment cases the terminals are used as monitoring points, which periodically share their monitoring data (e.g., capabilities description, configuration data, events, alarms, measurements) to the KP.

V. Instantiation of Reference Points

The GANA Reference Model defines Rfps between DEs as well as between DEs and other FBs. An Rfp is a logical interface between at least two FBs, over which Characteristic Information is exchanged (Fig. 5). This includes messages and data that characterizes what is communicated between the FBs.

Since the definition of Rfps within the GANA model is general, their instantiation for mesh networks must be precise and include a definition of protocols used to convey the characteristic information which also needs to be identified.

GANA DEs have “mirror” DEs at different levels to exchange information in order to collaboratively drive the autonomic control of various types of network resources. DEs at different levels (e.g., Network-Level and Node-Level) operate on different scales (in time and space) according to the

GANA hierarchical decision-making approach. Hence, from the mesh network perspective it is important to define goals, responsibilities and mechanisms for the exchange of Characteristic Information at particular levels both over the vertical interfaces, as well as over the horizontal ones (Fig. 5). The second case can be applicable to, e.g., the coordination of a mesh network composed of coexisting and/or collaborating regional zones, for which communication between DEs at the corresponding level is required.

The DEs need to communicate the following type of Characteristic Information: (a) "views" such as policy changes by the human operator; challenges to the network's operation from the perspective of a particular DE, e.g., events, detected faults, threats, etc.; (b) "views" communicated from lower level DEs in nodes that require Network-Level DEs to know and share, and (c) negotiations and synchronization of actions and policies.

According to the specifics of the information to be exchanged for the purpose of controlling the autonomic functions, it is expected that high layer protocols will be applied. This means that mainly XML-based protocols are considered for the instantiation of Rfps, but other solutions, such as IEEE 802.21 or SNMP are taken into account as well. For enhanced flexibility the MBTS service can be used in the Rfp implementation.

VI. Various Mesh Network Setup Scenarios and their Implication on Governance and Behaviors

The flexibility of the GANA mesh network should allow different setup scenarios according to the different players involved in this network, as well as the heterogeneous technology used [4][5]. The GANA governance mechanism allows knowing how the mesh network should be setup with common objectives. This implies that the administrative authority provisioning a mesh network is also provisioning a Knowledge Plane that covers the scope of this mesh network. Furthermore, as the GANA mesh network could interact with legacy infrastructure such as fixed or wireless networks the GANA mesh network should share is behavior with such networks.

The mesh network could be used to extend the coverage or the capacity of a small area network, such as a home network or at a football stadium. In this case the mesh network will be managed and secured by the Internet provider but also by the owner of the small area which provides the gateway to Internet and wireless connectivity. The fault diagnosis, the QoS monitoring, and the configuration could be managed by the Internet provider. This would mean that the KP that manages the mesh is provisioned and owned by the Internet provider. The mesh network should be governed according to the different players involved in the activation of the network. It is the task of AFI to list the types of players and determine the ones who own and provision the KP. This action should clearly take into accounts the industry's requirements.

The mesh network could also be used to provide a freedom

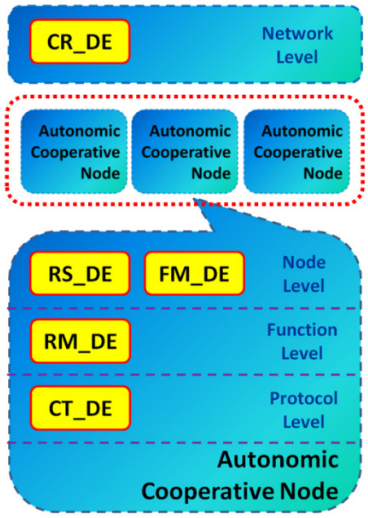

Fig. 6 Autonomic cooperative node from architectural perspective

Internet that can survive major outages (e.g., electricity, Internet connectivity) and is resilient during emergencies, natural disasters, or other hostile environments where conventional telecommunications networks are easily crippled. In this case the Knowledge Plane may not completely exist and the mesh network itself would have to self-organize and instantiate a "minimal" Knowledge Plane and its Functional Blocks in order to function without or with minimal governance. The mesh network could also provide democratic activists a secure and reliable platform to ensure their communications cannot be disabled by authoritarian regimes. For this particular use case the communication should provide protect data integrity, provide anonymity through strong end-to-end encryption and data aggregation.

Finally, the mesh network could also be used to connect heterogeneous nodes supporting various network technologies [6]. In this case it is necessary to understand how capabilities of individual devices are used to compose a network. According to [1], every autonomic node must self-describe and self-advertise capabilities (supported protocols, interfaces, features, etc.) to the ONIX and the Knowledge Plane would use the discovered capabilities to compose a network and give individual nodes the configuration profiles to apply according to the network type.

VII. Autonomic Cooperative Networking

Cooperative networking is a concept which is greatly facilitated by autonomic principles and serves as an example of cooperative relaying in a mesh topology. Cooperative transmission aims to improve the reliability of wireless communications through the use of diversity provided by relay nodes assisting in the transmission between other network nodes. This is possible as the rationale behind spatio-temporal processing can be easily mapped onto cooperative networking, as long as sufficiently tight synchronization is guaranteed. In fact, different cooperative and non-cooperative transmissions can take place at the same time [7]. The task of proper organization of such transmissions can be very demanding because it requires knowledge of both local and global scope parameters such as capabilities of specific nodes to expose certain behaviors (i.e., cooperation), the QoS related requirements of the end users, as well as the patterns according to which the network deployment and/or topology may change over time.

This issue may be solved according to the architectural extension of the GANA architecture (Fig. 6). First, it is assumed that the definition of the GANA autonomic node is enhanced with the notion of cooperation and so the autonomic cooperative node is introduced to accommodate the additional cooperation related decision entities [8]. At the Protocol-Level a new Cooperative Transmission Decision Element (CT_DE) is introduced which is responsible for controlling the aspects of the cooperative transmission protocol related to the physical emulation of distributed spatio-temporal block encoding. Its operation needs to be aligned with the already existing Routing Management DE (RM_DE) which needs to collaborate with its siblings so the routing tables maintained at the cooperating nodes are properly synchronized. The RM_DE also needs to act pursuant to the directions from the other existing DEs, i.e., the Resilience and Survivability DE (RS_DE) and Fault Management DE (FM_DE). In particular, the RS_DE is assumed to cover the aspects related to service resilience and survivability and to interact with the FM_DE responsible for controlling the symptoms suggesting that a failure, e.g., in terms of service, may be imminent. While those DEs are located at autonomic collaborative nodes, it is still necessary to provide substantial coordination at the Network-Level. This task is accomplished by the Cooperative Routing Decision Element (CR_DE) responsible for overseeing the situation from a higher level perspective and orchestrating the concurrent transmissions.

VIII. Conclusion and Further Work

This paper captures a work in progress of the ETSI AFI standardization group that specifies foundations for the deployment of autonomics in mesh networks. The standardization activity described is called instantiations of the AFI GANA reference model, the model being endorsed by the ETSI AFI group as the tool for deriving specific architectural frameworks in relevant telecommunications systems. The AFI GANA reference model has been developed as the universal and generic understanding and structure for deployment of autonomic functionalities.

The completion of the process of instantiations is covered in specific stages in the paper for the example mesh network. The first stage includes the awareness of the levels of DEs in the actual mesh networks and identifications of mesh-specific DEs. Then, the instantiation proceeds with consideration for the manner of execution of the KP for mesh networks. Hence, reasons are given for the overlay type of implementation of the KP in the networks in consideration. The next stage presented includes a layout and specifications of the Rfps between DEs and the KP, from their generic nature described in the AFI GANA reference model, to roles in the instantiated autonomic mesh networks architecture. The instantiation stage with consideration for Reference Points is to provide frameworks for information exchange that would then accommodate specific implementation solutions. Finally, with an autonomic architecture structure derived using the instantiation process, it enables the organization of the governance issues for control and monitoring of the network's operations with policies and goals set by the human operator. The autonomics architecture in place is to guide the network behavior with trustworthy mappings of business to service and then technical objectives.

The paper also discusses example mesh network scenarios where the autonomics can be deployed in real situations. It is noted that the mesh network chosen and elaborated in the paper as the instantiation target, serves to demonstrate a clear and current work in progress of the group. However, the scope of the group's activities and the applicability of the AFI GANA reference model extend to various types of telecommunications systems. Similar processes of instantiations to other telecommunications systems (e.g., cellular networks) are being conducted by the group. Finally, the autonomics feature being standardized by the group are to foster specific solutions (e.g., information exchange protocols in Rfps, DE's computer intelligence and algorithms, KP information modeling, control and management plane protocols in the telecommunications systems) as they are intended as enablers of further implementation-specific design and frameworks for expansion of future networks capabilities with embedded autonomic capabilities. As discussed in [9] various stakeholders are required to join the ongoing standardization efforts and contribute to a faster pace of maturity and adoption of standards while contributing to the evolution of these standards.

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