ETSI TR 103 495 V1.1.1 (2017-02)

TECHNICAL REPORT

**Network Technologies (NTECH);
Automatic network engineering
for the self-managing Future Internet (AFI);
Autonomicity and Self-Management
in Wireless Ad-hoc/Mesh Networks:
Autonomicity-enabled Ad-hoc and
Mesh Network Architectures**

Reference
DTR/NTECH-AFI-0018-GANA-MESH

Keywords
architecture, autonomic networking,
self-management, wireless ad-hoc network,
wireless mesh network

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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Network Technologies (NTECH).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

The distributed nature of Wireless Mesh Networks (WMNs) allows them to benefit from multiple autonomic functionalities. However, the existing landscape of self-x solutions (e.g. self-configuration) is fragmented and the lack of a standardized framework through which interoperable autonomics can be developed has been hampering adoption and deployment of autonomics in real world service networks. There is a need for a standardized architectural framework that enables to comprehensively support and integrate interoperable components for autonomicity in WMNs. Such an architecture (autonomicity-enabled wireless mesh architecture) is the subject of the present document.

The proposed autonomic wireless mesh architecture is an instantiation of the GANA (Generic Autonomic Network Architecture) Reference Model - a standards based approach to autonomics, onto the wireless mesh network architecture. The provided guidelines can now help researchers and engineers build autonomicity-enabled WMNs using a standardized framework that enables adoption and deployment of autonomics by industry, thereby enabling researchers and engineers to contribute to further evolution of the framework described in the present document in ETSI. It has to be noted that the same approach being applied to introducing autonomics in mesh networks in the present document also applies to Ad-hoc wireless networks, and so the present document covers both aspects - hence the document title "Autonomicity and Self-Management in Wireless Ad-hoc/Mesh Networks: Autonomicity-enabled Ad-hoc and Mesh Network Architecture".

The GANA model is being instantiated onto various reference network architectures to create autonomics-enabled reference network architectures. For example, ETSI recently published ETSI TR 103 404 [i.17], which addresses Autonomicity and Self-Management in the Backhaul and Core network parts of the 3GPP Architecture through GANA instantiation onto the Backhaul and Core (EPC) network parts of the 3GPP architecture. Readers may also find ETSI TR 103 404 [i.17] helpful in further understanding how GANA is being applied in various networks. Readers may also follow up on ongoing work in ETSI on instantiation of the GANA onto the Broadband Forum (BBF) architectures that incorporate SDN (Software-Defined Networking) and NFV (Network Functions Virtualization). To obtain some guidance and information on the various types of stakeholders who should get involved and contribute to standards on self-managing future networks, readers may refer to [i.6] and [i.15].

1 Scope

The present document aims to provide recommendations for the introduction of autonomics (management and control intelligence) into Ad-hoc and Mesh Network architectures and their associated management and control architectures.

The present document describes:

- Autonomicity-enabled Ad-hoc and Mesh Network Architecture that is a result of the instantiation of the GANA (Generic Autonomic Networking Architecture) Reference Model on the Ad-hoc and Mesh Network architecture to enable developers of autonomics to introduce autonomics in the architecture
- Relevant autonomicity-enabled functions and operations
- Relevant GANA Decision Elements (DEs) and Reference Points between those DEs

The present document describes the specific desirable features for autonomic management and control of Ad-hoc and mesh network functions through the introduction of Decision Elements (DEs) and their associated control loops at the Network, Node and Function level of the GANA reference model. The Protocol level needed to be additionally addressed due to the need for accommodating the specifics of Ad-hoc and mesh set-ups.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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[i.6] Ranganai Chaparadza, Tony Jokikyyny, Latif Ladid, Jianguo Ding, Arun Prakash, Said Soulhi: The diverse stakeholder roles to involve in Standardization of Emerging and Future Self-Managing Networks: In proceedings of the 3rd IEEE MENS Workshop at IEEE Globecom 2011: 6-10 December 2011, Houston, Texas, USA.

[i.7] ETSI GS AFI 001 (2011-06): "Autonomic network engineering for the self-managing Future Internet (AFI); Scenarios, Use Cases and Requirements for Autonomic/Self-Managing Future Internet".

[i.8] IEEE 802.11™: "IEEE Standard for Information technology--Telecommunications and information exchange between systems Local and metropolitan area networks--Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

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[i.18] ETSI TS 103 194: "Network Technologies (NTECH); Autonomic network engineering for the self-managing Future Internet (AFI); Scenarios, Use Cases and Requirements for Autonomic/Self-Managing Future Internet".

[i.19] ETSI GS AFI 002 (V1.1.1): "Autonomic network engineering for the self-managing Future Internet (AFI); Generic Autonomic Network Architecture (An Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management)".

NOTE An Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management.

[i.20] IEEE 802.21™: "IEEE Standard for Local and metroploitan area networks - Media Independent Handover Services".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

Autonomic Behaviour (AB): process which understands how desired Managed Entity (ME) behaviours are learned, influenced or changed, and how, in turn, these affect other elements, groups and networks [i.18]

NOTE: In the GANA model, an autonomic behaviour is any behaviour of a DE that is observable on its interfaces. A GANA DE is also called an Autonomic function (AF).

autonomic networking: networking paradigm that enables network devices or elements (physical or virtual) and the overall network architecture and its management and control architecture to exhibit the so-called self-managing properties, namely:

- auto-discovery of information and entities
- Self-configuration (auto-configuration), Self-diagnosing, Self-repair (Self-healing)
- Self-optimization, and other self-* properties

NOTE 1: Autonomic Networking can also be interpreted as a discipline involving the design of systems (e.g. network nodes) that are self-managing at the individual system levels and together as a larger system that forms a communication network of systems.

NOTE 2: The term "autonomic" comes from the autonomic nervous system (a closed control loop structure), which controls many organs and muscles in the human body. Usually, humans are unaware of its workings because it functions in an involuntary, reflexive manner - for example, humans do not notice when their heart beats faster or their blood vessels change size in response to temperature, posture, food intake, stressful experiences and other changes to which human are exposed. And their autonomic nervous system is always working [i.18].

Decision Making Element (DME): functional entity designed and assigned to autonomically manage and control its assigned Managed Entities (MEs) by dynamically (re)-configuring the MEs and their configurable and controllable parameters in a closed-control loop fashion

NOTE 1: Decision Making Elements (DMEs) [i.19] referred in short as Decision Elements (DEs) fulfil the role of Autonomic Manager Elements.

NOTE 2: In GANA a DE is assigned (by design) to very specific MEs that it is designed to autonomically manage and control (ETSI GS AFI 002 [i.19] provides more details on the notion of ownership of MEs by specific DEs required in a network element architecture and the overall network architecture).

Managed Entities (MEs): physical or logical resource that can be managed by an Autonomic Manager Element (i.e. a Decision Element) in terms of its orchestration, configuration and re-configuration through parameter settings [i.18]

NOTE: MEs and their associated configurable parameters are assigned to be managed and controlled by a concrete DE such that an ME parameter is mapped to one DE. MEs can be protocols, whole protocol stacks, and mechanisms, meaning that they can be fundamental functional and manageable entities at the bottom of the management hierarchy (at the fundamental resources layer in a network element or node) such as individual protocols or stacks, OSI layer 7 or TCP/IP application layer applications and other types of resources or managed mechanisms hosted in a network element (NE) or in the network in general, whereby an ME exposes a management interface through which it can be managed. MEs can also be composite MEs such as whole NEs themselves (i.e. MEs that embed sub-MEs).

overlay: logical network that runs on top of another network

EXAMPLE: Peer-to-peer networks are overlay networks on the Internet. They use their own addressing system for determining how files are distributed and accessed, which provides a layer on top of the Internet's IP addressing.

self-advertising: capability of a component or system to advertise its self-model, capability description model, or some information signalling message (such as an IPv6 router advertisement message) to the network in order to enable other entities to discover it and be able to communicate with it, or to enable other entities to know whatever is being advertised

self-awareness: capability of a component or system to "know itself" and be aware of its state and its behaviours

NOTE: Knowledge about "self" is described by a "self-model".

self-configuration: capability of a component or system to configure and reconfigure itself under varying and unpredictable conditions

self-healing: capability of a component or system to detect and recover from problems (manifestations of faults, errors, failures, and other forms of degradation) and continue to function smoothly

self-monitoring: capability of a component or system to observe its internal state, for example by monitoring quality-of-service metrics such as reliability, precision, rapidity, or throughput

self-optimization: capability of a component or system to detect suboptimal behaviours and optimize itself to improve its execution

self-organizing function: function that includes processes which require minimum manual intervention

self-regulation: capability of a component or system to regulate its internal parameters so as to assure a quality-of-service metric such as reliability, precision, rapidity, or throughput

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	3rd Generation Partnership Project
AF	Autonomic Function
AFI	Autonomic network engineering for the self-managing Future Internet
AMC	Autonomic Management and Control
AN	Access Network
BBF	BroadBand Forum
CA	Collision Avoidance
CM DE	Cooperation Management Decision Element
CM	Cooperation Management
CM-DE	Cooperation Management Decision Element
CO DE	Cooperation Orchestration Decision Element
CO	Cooperation Orchestration
COTS	Commercial-Off-The-Shelf
CR DE	Cooperative Relaying Decision Element
CR	Cooperative Relaying
CR-DE	Cooperative Relaying Management-Decision Element
CSMA	Carrier Sense Multiple Access
DE	Decision-making-Element
DP&F	Data Plane and forwarding
DSTBC	Distributed Spatio-Temporal Block Coding
E2E	end-to-end
EDCA	Enhanced Distributed Channel Access
EMS	Element Management System
EPC	Evolved Packet Core
FB	Functional Block
FM DE	Fault Management DE
FM	Fault Management Decision Element
GANA	Generic Autonomic Network Architecture
GCP	Generic control Plane management
GS	Group Specifications
GUI	Graphical User Interface
GW	GateWay
HRP	Horizontal reference point

HWMP	Hybrid Wireless Mesh Protocol
KP	Knowledge plan
MAN	Mesh Access Node
MANET	Mesh Ad-hoc Network
MBTS	Model Based Translation Service
MCCA	MCF (Mesh Coordination Function) Controlled Channel Access
MCF	Mesh Coordination Function
ME	Managed Entity
MGW	Mesh Gateway
MN	Mesh Node
MPR	Multi-Point Relay
MRN	Mesh Relay Node
NFC	Near Field Communications
NMS	Network Management System
OLSR	Optimised Link State Routing
ONIX	Overlay Network Information Exchange
PDP	Policy Decision Point
PREQ	Path Request
QoS	Quality of Service
RFID	Radio Frequency Identification
Rfps	Reference Points
RM DE	Routing Management DE
RR-DE	Re-Routing Decision Element
RS DE	Resilience and Survivability DE
RS	Resilience and Survivability
RTS/CTS	Request to Send/Clear to Send
SDN	Software Defined Networking
SNMP	Simple Network Management Protocol
SO	Self-Optimization
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
VCS	Virtual Cooperative Sets
VRP	Vertical Reference point
WAN	Wide Area Network
WMN	Wireless Mesh Network

4 GANA Reference Model

4.1 Background

The GANA Reference Model defines Functional Blocks (FBs) and the associated Reference Points (Rfps). These elements are specific to enabling autonomics, cognition, and self-management in target architecture, when instantiated onto implementation-orientated reference architecture such as the architectures defined by standardization organizations (3GPP, BBF, ITU-T, and IEEE).

Figure 1 presents a general overview of the GANA reference model while its details, related concepts and its evolution are described in [i.18], [i.1], [i.2]. Note that in reference to Figure 1, HRP means Horizontal Reference Point, while VRP means Vertical Reference Point.

The ETSI White Paper No.16 [i.16] is a good source for a brief description of the GANA, including how it integrates with emerging networking paradigms of SDN (Software Defined Networking), Network Functions Virtualization (NFV), E2E (End-to-End) Service Orchestration and Big-Data analytics for driving management and control of networks and services.

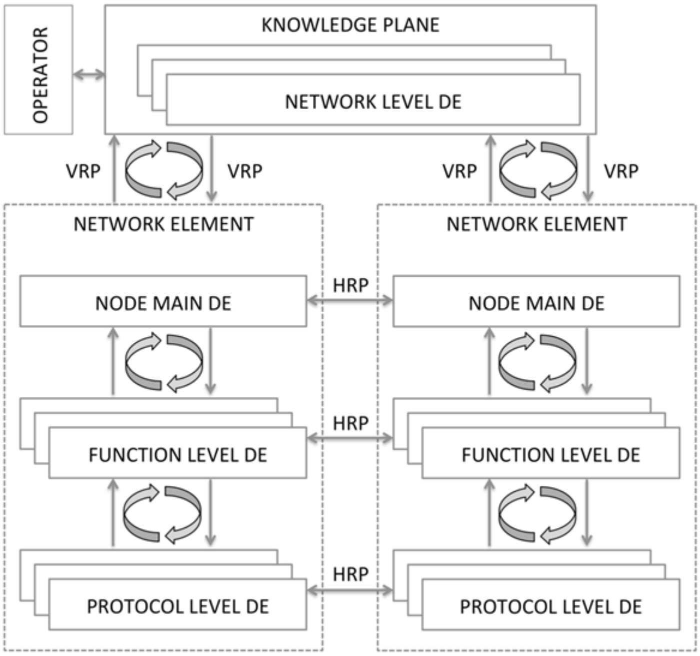


Figure 1: GANA reference model

Self-manageability in GANA is achieved through instrumenting the devices with autonomic Decision-making-Elements (DEs), which automate network operations by implementing control loops (Figure 2). Such control loops operate using the knowledge regarding events and the state of network resources. They regulate the resources or functions of the network according to its goals.

GANA defines the DE as a concept that is associated with (one or more) concrete resources managed by the DE, and implements and drives its control loop based on a continuous learning cycle. At the same time, the DEs are continuously exposed with a local view of their managed resources, together with other cognition functions which retrieve knowledge from other required or potential information suppliers of DEs, such as the environment in which the device hosting the DE is operating.

These functions are used by the autonomic element to change the behaviour of the managed resources in order to achieve and maintain the goals known by the autonomic element. GANA also adopts the concept of a Managed Entity (ME) to denote a managed resource or an automated task in general, instead of a Managed Element, in order to be more generic and to avoid the confusion arising when one begins to think of an element as only meaning a physical network element.

As outlined in Figure 1, GANA defines four basic levels of abstractions at which autonomicity can be introduced, namely:

- Protocol-Level (GANA Level-1);
- Function-Level (GANA Level-2);
- Node-Level (GANA Level-3);
- Network-Level (GANA Level-4).

Since the Protocol-Level involves embedding an intrinsic control loop within an individual protocol, it may not be necessary to introduce such "intelligence" into individual protocols, but rather to focus on introducing autonomicity (control loops) at higher levels of abstraction, starting from the level directly above (i.e. the Function-Level that defines "functions" which abstract individual protocols and mechanisms), up to the Network-Level. This makes the three levels (Level-2 to 4) the most important ones. Therefore, according to the Reference Model (Figure 1), the three levels of hierarchical control loops that are realized by corresponding Decision-making-Elements (DEs) work collaboratively, from within a Network-Element up to the Network-Level (Knowledge Plane), demonstrate how autonomics, cognition, and self-management can be gracefully (i.e. non-disruptively) introduced in today's existing architectures.

In fact, one of the key inherent features of an autonomic system is the need for continuous monitoring so that a networked system is able to self-manage according to the internally or externally imposed policies while taking into account additional information, such as the one related to root causes and incidents, the use of which may substantially improve the overall system dependability and resilience through proper fault-management [i.14]. The aforementioned factors are particularly important for distributed wireless networks such as Mobile Ad-hoc NETworks (MANETs) and Wireless Mesh Networks (WMNs), which have varying parameters (e.g. radio link quality, topology, traffic patterns) that affect the ability of networked nodes to efficiently express Autonomic Behaviour facilitated through cooperation. In other words, from a general viewpoint, such an Autonomic Networking should imitate the behaviour of a living organism's autonomic nervous system in terms of being continually driven by a substantial number of processes, similarly to the Autonomic Nervous System, i.e. running on their own but remaining in close correlation without any specific need for orchestration from a central entity for most of the time of operation [i.15].

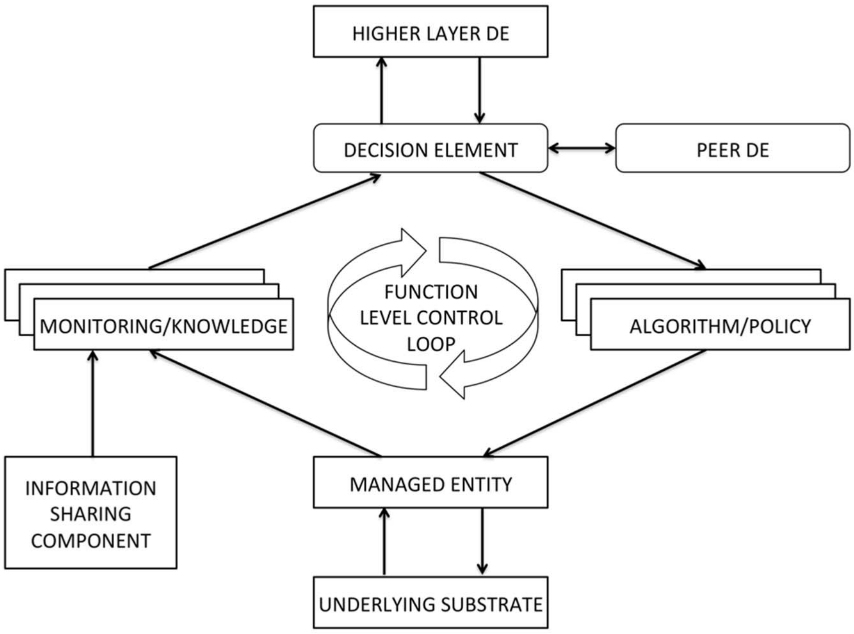


Figure 2: Example generic autonomic control loop (at the function level in GANA)

In particular, as mentioned above, in order to introduce or advance autonomicity in any network architecture, an instantiation needs to be carried out of the FBs and Rfps from the GANA Reference Model onto a target architecture, e.g. the MANET and WMN architectures considered herein. This instantiation implies the following tasks:

1) It is necessary to instantiate the FBs of the Knowledge Plane, which consist of the Network-Level DEs (as described above) with cognition functions able to expose the local view and able to aggregate different views to retrieve a global view of the behaviour of the network, the Model-Based-Translation Service (MBTS), and the Overlay Network for Information eXchange (ONIX). MBTS forms an intermediation layer between the Knowledge Plane and the network elements. ONIX is a distributed scalable system of information servers that supports the publish/subscribe paradigm for information exchange and discovery [i.19].

2) Regarding Network-Level DEs: they can perform the role of Policy-Decision Points (PDPs) and such PDPs can be evolved by the Decision Elements. Additionally, Network-Level DEs (in the Knowledge Plane) either evolve EMSs/NMSs or may be implemented as separate run-time entities that then interwork with these EMSs or NMSs.

3) GANA's Knowledge Plane may complement the existing OAM/OSS Plane by:

    a) the ONIX information exchange servers which facilitate, through publish/subscribe services, an advanced self-awareness of the elements plugged into the network, their capabilities, network resources, configuration-data/profiles/policies, pointers to information and resources, etc.; and

    b) establishing the type of autonomic functions (i.e. DEs, their associated control loops and their assignment to specific MEs, as well as parameters they manage and adaptively control) that should be instantiated onto which Network Elements.

Finally, regarding the end-to-end transport architecture it is necessary to establish the required kinds of distributed control loop coordination and use the instantiated FBs and Rfps for autonomicity/self-management from the reference model, to specify autonomic behaviours (i.e. behaviours of instantiated DEs) within the management and the E2E transport architecture.

4.2 A possible approach for the implementation of this GANA instantiation

4.2.1 Overview

Given the requirements in terms of the envisaged complexity imposed by the GANA Reference Model depicted in Figure 1, the differences between both the Ad-hoc and mesh types will increase the closer to the GANA protocol level. In order to facilitate the standardisation effort it has been decided that the process of the instantiation of the Autonomicity-enabled Ad-hoc and Mesh Network Architecture be split into cases starting from the most generic knowledge plane, going through the function level, and ending up at the protocol level. Yet, at the same time, such a methodology does not exclude the inclusion of certain exemplary lower level, such as the protocol level, instantiations of the respective Decision Elements, belonging either to the Ad-hoc or mesh part. All the said stages are described below. The usage of the notion of cases instead of stages allows for parallel work, as normally it would be expected that a stage be completed before the next may be started.

4.2.2 Case 1 - Knowledge Plane Level Autonomicity (Control-Loops)

The first case (Figure 3a) is the most generic one where the highest extent of synergy is expected between both the components of the Autonomicity Enabled Ad-hoc and Mesh Network Architecture.

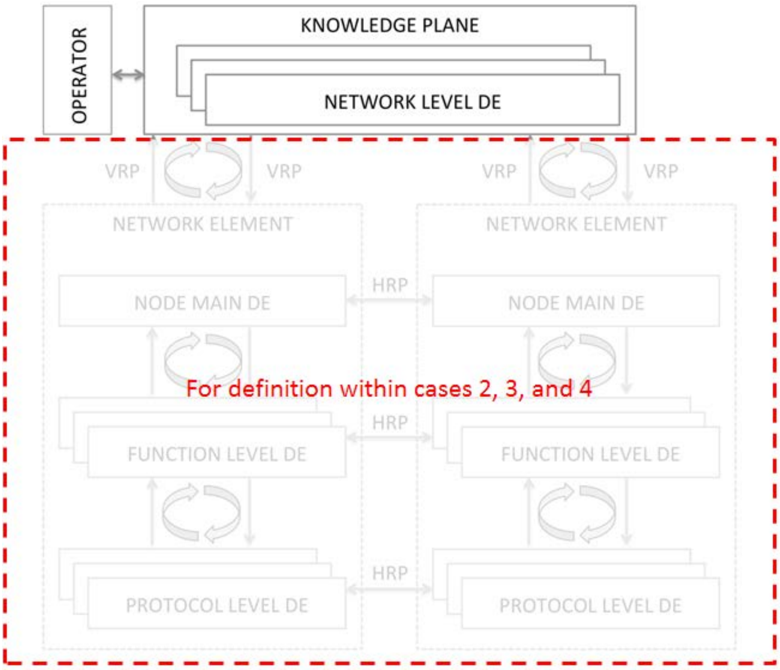


Figure 3a: Case 1 - Knowledge plane

4.2.3 Case 2 - Node Level Autonomicity (Control Loops)

The second case (Figure 3b) looks into the node level being located immediately below the network level with more of a virtual nature.

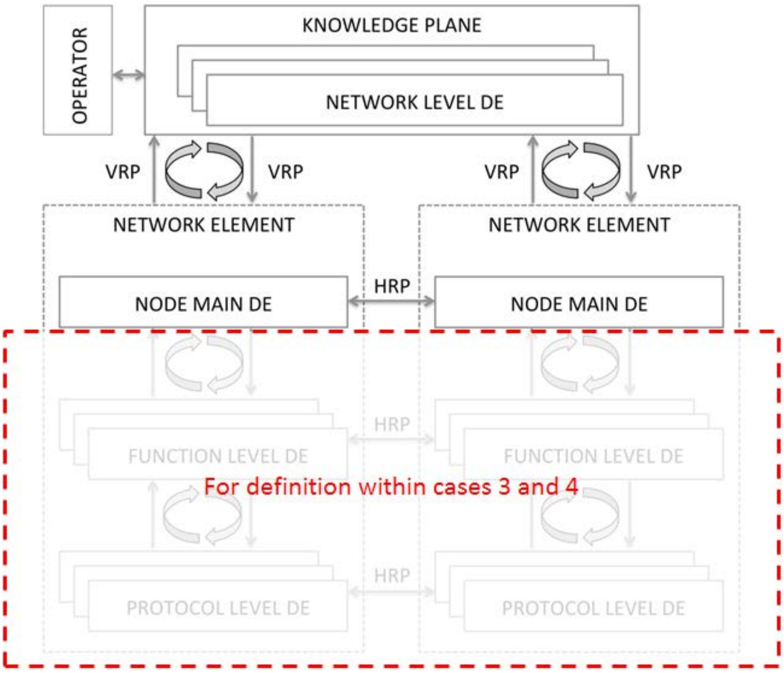


Figure 3b: Case 2 - Node level

4.2.4 Case 3 - Function Level Autonomicity (Control Loops)

The third case (Figure 3c) goes as deep as to the function level where the feasibility of integration still appears to be achievable thanks to certain degree of a functional similarity between both the Ad-hoc and mesh networks.

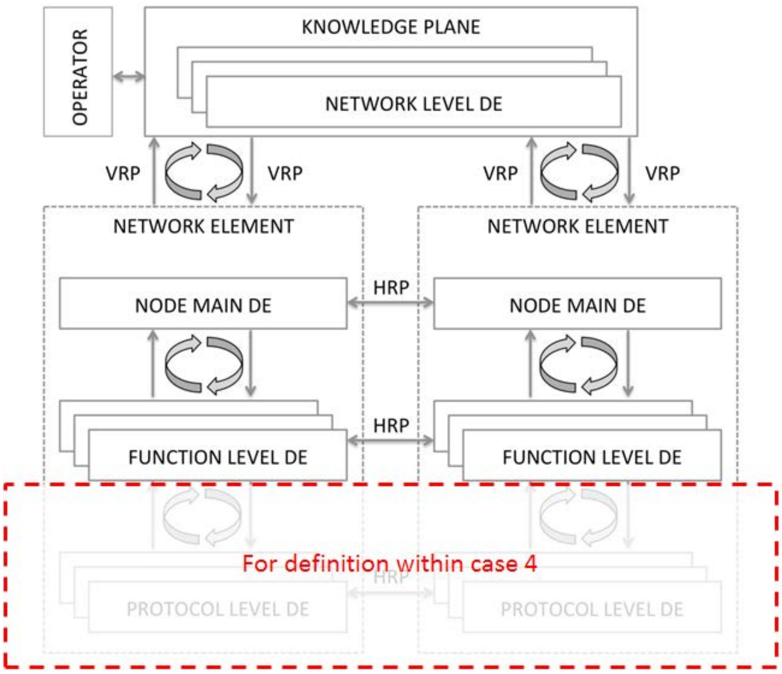


Figure 3c: Case 3 - Function level

4.2.5 Case 4 - Protocol Level Autonomicity (Control Loops)

The protocol level (GANA level 1) (Figure 3d) has been assigned to the fourth case being the most demanding one as the specific protocols related to Ad-hoc and Mesh networks become the critical differentiating point. However for Ad-hoc network the level 2 and level 3 DEs in GANA may be the better way to implement the distributed algorithms for self X features, and this may complement the autonomics intrinsically implemented into protocol level.

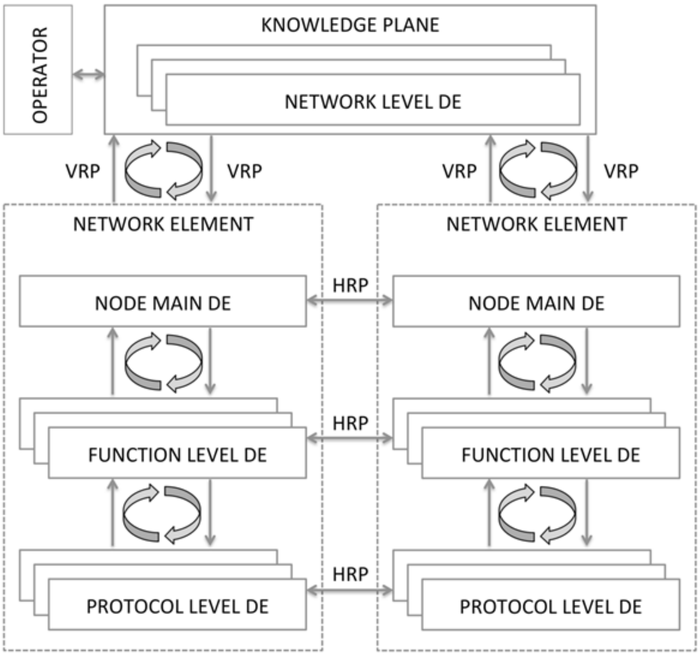


Figure 3d: Case 4 - Protocol level

4.3 Stability and Coordination of Autonomic Functions

For addressing stability and coordination of autonomic functions (AFs), the ETSI GS AFI 002 [i.19] includes techniques and architectural principles that ensure that control loops can be designed in a way that guarantees non-coupling and/or non-conflicting behaviours of autonomic functions (e.g. by time-scaling, ordered decisions), so as to ensure stability. Following the principles defined in [i.19], and in particular, the concept of DE ownership of an ME or ME Parameters, a DE-to-ME Parameters Mapping Table is required for each instantiation of the reference model onto the target node/device architecture. A table per node type or device type should be provided. For all the MEs and parameters at the resources layer of a node/device, Table 1 should provide a one-to-one mapping of a particular configurable and controllable parameter of an ME to a single DE (Figure 4). This mapping is important for the reasons described below, and should be included in the associated standard emerging from the instantiations of the reference model onto a particular reference architecture. This mapping plays an important role at the design time for DE behaviours, as well as in realizing the coordination and collaboration of autonomic functions.

The DE-to-ME-Parameters Mapping Table is obviously important to DE designers. By referring to Table 1, a DE designer who designs the behaviour of the autonomic manager, can see the parameters that the DE can configure and dynamically control. This dynamic adjustment may require that the DE performs synchronization, collaboration, and coordination with other DEs on the same GANA level or on a higher level. The mapping table will also be used by an editor, simulator or validator to enforce constraints on which a given DE is allowed to modify a parameter value of an ME. The table can be imported into a simulation and validation environment, i.e. a development environment in which DEs are designed and their behaviours simulated and validated for autonomic behaviour functionality and also validated against potential stability related problems [i.19]. In the development, simulation and validation environment, the editor, i.e. the Graphical User Interface (GUI) used by DE designers, can be made to import the mapping table in order to enforce constraints on the permissions of the DE designer when setting parameter values for MEs. The constraints can also be enforced within the simulator or validator or a conflicted resolution survey FB in the KP. Alternatively, the constraint checker can relax the constraint by allowing a DE to request parameter value change indirectly via another DE that owns the ME parameter, as described below.

The coordination of autonomic functions (DEs) is done in a twofold manner. First, DEs perform coordination on which parameters (i.e. values) should be changed under given circumstances as guided by a shared optimization and self-adaptation objective commonly understood by the DEs. The coordinating DEs may conclude to change certain parameter values in different time scales or re-order the different hierarchical DEs. The DE that is assigned to manage and control a particular parameter is the one that adjusts the parameter setting after the coordination process of various DEs required to coordinate is completed. Second, indirect parameter adjustments can occur by allowing a designer of a DE logic to indirectly change a parameter value in the logic of the controller by making calls to the DE responsible for managing and controlling the parameter (the owner DE of the parameter). The intercepting DE (the parameter owner) can decide to make the parameter value change, reject it or postpone the requested change.

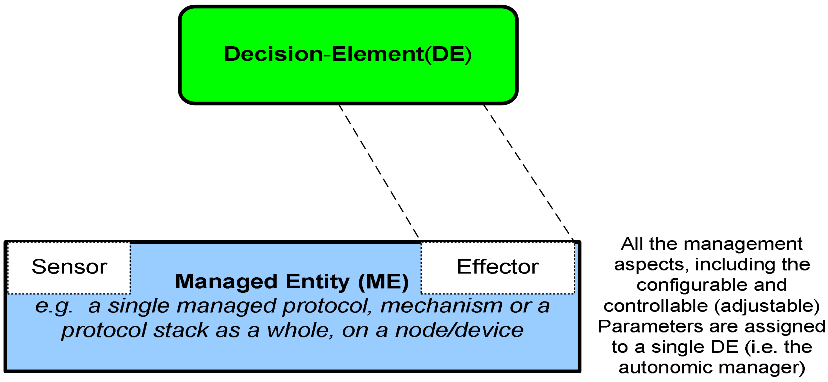


Figure 4: Parameter mapping Case 1 (preferred mapping): an ME is fully assigned to a single DE, i.e. the ME effector assigned to a single DE)

Figures 4 and 5 show how MEs and their parameters can be assigned to particular DEs for Autonomic Management and control (AMC). The figures show how GANA is working on creating the DE-to-ME-Parameters Mapping Table **(e.g. Table 1)** for the various node types on which a GANA instantiation has been performed. The partitioning can be driven by the various ME's management aspects and parameters being perceived as "abstracted" by multiple DEs when mapped to the GANA abstractions at Level-2 and Level-3.

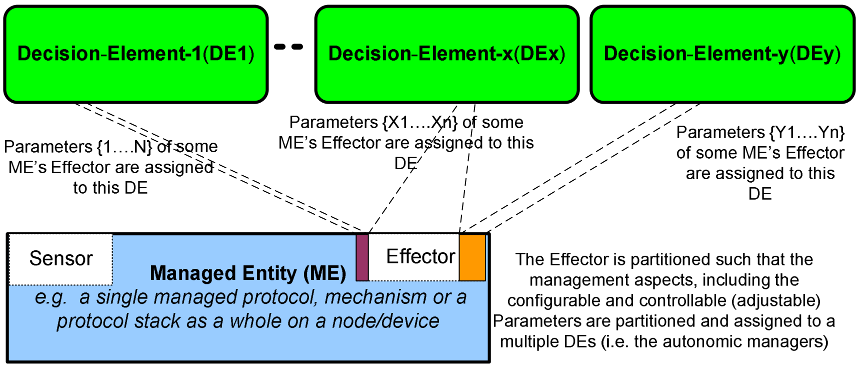


Figure 5: Parameter mapping Case 2: an ME with an effector partitioned such that varying parameter sets are assigned to different DEs)

The ME may exhibit multiple configurable characteristics, e.g. it can be viewed as an "instrument" for enforcing QoS, security, or mobility through a given parameter configuration. Therefore, there is the question of whether to wholly assign the ME to the QoS-Management-DE, Security-Management-DE or to the Mobility-Management-DE or other relevant DE. But to avoid complexity, the partitioning of the ME effector could be avoided by following the Case 1 option, and enforcing any designed DE logics to coordinate through a single DE owner of the whole ME. In Case 2 (Figure 5), the DEs need to synchronize their operations and coordinate their parameter value manipulations and, if necessary, also the time scaling for those parameter value modifications, to ensure that the overall behaviour of the ME is desirable and fulfils the ME's objectives.

4.4 Governance - Profiles and Policies

The enabling notion of governance is based on the fact that the autonomic network requires as input goals and requirements defined by the human operator. The network should operate with respect to the operator business rules and the operator should trust the autonomic network behaviour.

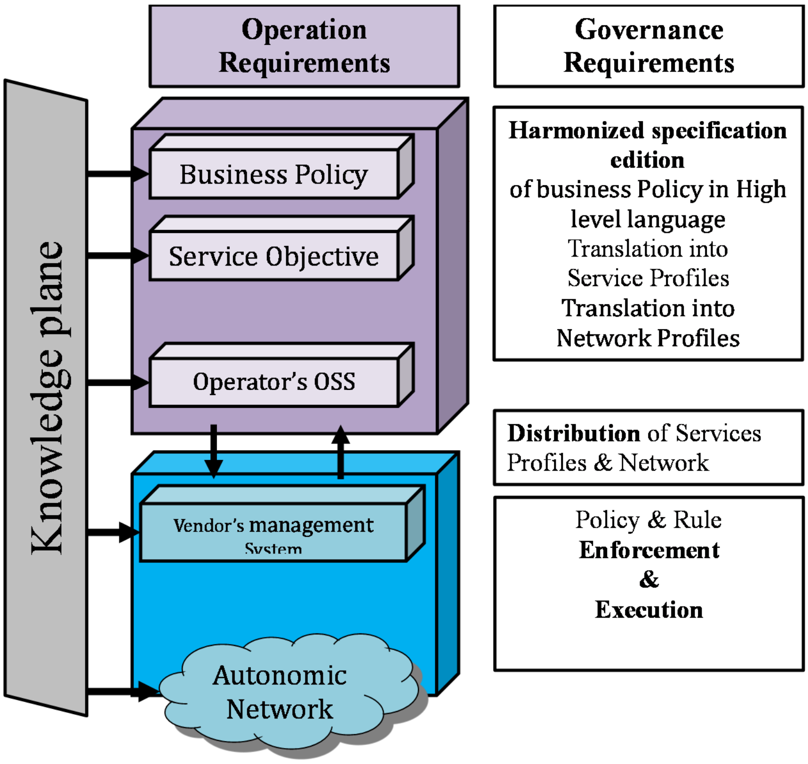


Figure 6: GANA governance model

Therefore, the GANA governance mechanism (Figure 6) enables the human operator to define business policies and validate the policies and profile disseminated by the network governance mechanisms. The business profiles are mapped within a service profile down to technical policies applied in a vendor specific element format for acting as the business provider desires. A common generic model is used to translate the common objectives identified by the business in a specific profile and policy in legacy domain, vendor, and provider solutions.

The aim of this mechanism is to guarantee that the GANA reference model is able to achieve manageable autonomicity in order to be able to guide network behaviour. Moreover, this procedure can be based on an explicit policy management framework for guiding infrastructure and controlling the network entities. Both policy- or goal-based management approaches may be applied.

The GANA model is also used to self-describe the capabilities of any managed element and each Function-Level DE in order to build the knowledge of the capabilities of the network up to the business capabilities of a player [i.3]. The configuration map is used to translate the vendor specific description into a common GANA description useable in the domain where the network element will be connected to. The node main DE is responsible for aggregating the different capabilities and setting the main role of the nodes and the possibility role the Network-Level DE is decide which roles a node has to perform in the network according to the policies and goals retrieved by the governance mechanisms.

The GANA governance model supports a continuum policy and profile up to the business down to specific network element model. The GANA governance model can also exchange knowledge with cognitive function with the different players involved in delivering services to customers. As nowadays services are delivered with a composition of players, the GANA governance model will be facilitated by the integration of any services provided by any actors (even customers) in order to deliver to users a package of services provided by different players but adapted to the user context [i.4]. However, the cognitive functions exchange only the authorized knowledge in a secure way in order to avoid any disclosure of sensitive knowledge of the different actors [i.3]. The GANA governance model is finally used to trust the autonomic network by human operators [i.5].

The Network-Level DE aggregates the different decisions in the network and notifies the human on the current situation of the network. The operator can view the decision of the different DE in the network but can also interact with decisions if he wants to. The operator should validate only Network-Level DE which provides long term decisions. However, real time decisions or decisions already trusted by providers should not be validated in real time by human providers. In any case the human should be able to modify or disable decisions even those that were not notified to the provider for validations. This mechanism will allow the provider to manage its network by validating any un-trusted DE decision until it trusts those DEs. It allows the provider to learn and know how the network will be self-managed before it will really be self-managed without human interactions. This mechanism will also allow the provider to use its legacy management tool to manage its network in case he wants/needs to.

5 Autonomicity enabled Ad-hoc and Mesh Network Architectures

5.1 Background

The most generic difference among both the Ad-hoc and mesh networks consists in the fact that in the former case all nodes are mobile while in the latter one group of nodes remains stationary (forming a backbone) while other nodes are free to roam this network. Nonetheless, in both approaches there is a certain dose of dynamism which for the Ad-hoc network type translates, in general, into three distinct classes of routing protocols (which are one of the key distinguishing functionalities of such wireless multi-hop networks):

1) There is a proactive approach where each network node performs topology recognition on a regular basis in order to keep the routing tables always up-to-date. Unfortunately, unless optimised, such an approach might turn out costly in terms of the said control overhead.

2) A reactive approach exists in the case of which the operation of topology recognition is performed solely when the routing table needs to be updated. Consequently, the control overhead may be reduced, but, on the other hand, the delay related to selecting a proper route is bound to increase.

3) Finally, there is a hybrid approach which combines the advantages of both the aforementioned classes by applying either of them in accordance with the activity of mobile networked nodes in specific regions. As long as the topology changes remain insignificant, the reactive attitude may be more appropriate, otherwise, when the dynamism raises, the proactive one is used [i.14].

At the same time, IEEE 802.11 [i.8] 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 cultural performances or sport events). Moreover, wireless mesh networks (but also other architectures) provide an excellent example architecture for demonstrating the GANA instantiation process boosted by:

a) the availability of commercial-off-the-shelf (COTS) devices with plug & play capabilities;

b) the existence of functionalities that offer the opportunities to introduce autonomicity such as self-awareness (neighbourhood discovery), self-configuration (peer establishment), self-optimization (channel management) etc.; and

c) also by the fact that such networks already embed by design some self-* capabilities such as self-discovery and self-configuration.

The instantiation process, described here, is expected to present to the mesh networking community an "Autonomicity-Enabled Ad-hoc and 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 and the governance and the associated reference points in both wireless Ad-hoc and mesh networks.

In the opposite direction, by adopting and applying GANA framework, the Ad-hoc and mesh networking communities 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 Ad-hoc and mesh networking community can map their own work onto this particular autonomicity-enabled Ad-hoc and 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. A typical Ad-hoc or mesh network consists of several nodes equipped with wireless interfaces providing network connectivity from access nodes through the gateway to the core network. While usually the whole mesh network is operated by a single provider offering a relaying service for other providers or simply regular Internet access to end-users, its Ad-hoc counterpart should be perceived as being more of an infrastructure-less nature, where those are the end users devices to instantiate the network.

In both cases, the network topology can be dynamically established and dynamically reconfigured by the mechanism of enabling or disabling particular radio connections, i.e. links between nodes, which for the Ad-hoc type is escalated even further by the natural node mobility. This way or another, the most important feature of both the Ad-hoc and mesh networks is their extendibility and interoperability, but in order to fully benefit from such an ability the autonomic system design principles, such as disseminating local knowledge and self-organizing mechanisms, are required to be implemented within the Ad-hoc/mesh protocol stack.

A generic topology, applicable to both cases of Ad-hoc and mesh networks is depicted in Figure 7. Most naturally, it consists of interconnected generic networked nodes equipped with at least one wireless interface. In particular, there are three types of nodes in the mesh mode. The Mesh Gateway (MGW) is a node connecting the mesh network to the Wide Area Network (WAN). WAN access may be either wireless or fixed. The Mesh Access Node (MAN) is a node capable of offering network access service to end users. MAN is 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.

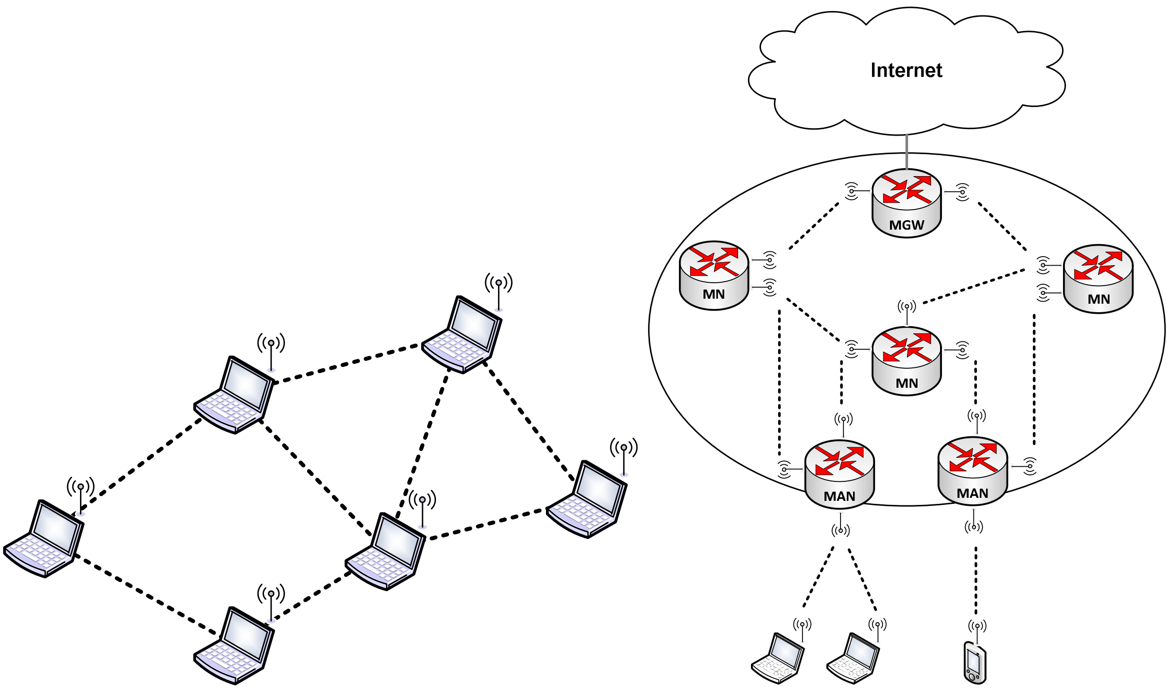


Figure 7: Common aspects between Ad-hoc (*left*) and mesh networks (*right*) include multi-hop wireless transmission

As such, on the one hand, mesh networks differ from the typical Ad-hoc or infrastructure operational modes of IEEE 802.11 [i.8] networks, yet, on the other hand, the most recent extensions, such as the IEEE 802.11s one, appear to bridge the gaps allowing for a joint architectural autonomic overlay to be standardized accommodating for the two. However, such a comprehensive approach needs to accommodate the following specific assumptions of the mesh approach:

- Mesh nodes are stationary, so that the relevant routing protocols normally do not take mobility aspects into account.

- Mesh nodes have regular power-supply, so power-saving issues, such as a forced rerouting in case of a low-energy node state needs to be additionally taken into account.

- 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 neighbouring nodes (based on the number of its interfaces).

5.2 Instantiation of GANA Functional Blocks

The GANA reference model defines a framework and a structure facilitating the specification and design of the relevant Functional Blocks (FBs), which are specific to realize autonomicity, and self-management, and maybe cognition. Individual Functional Blocks could be seen as functional elements, or architectural components, performing certain functions. In the GANA model standardisable "autonomic behaviours" refer to fundamental behaviours of FBs 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 and any other self*-operations. This includes how the 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.

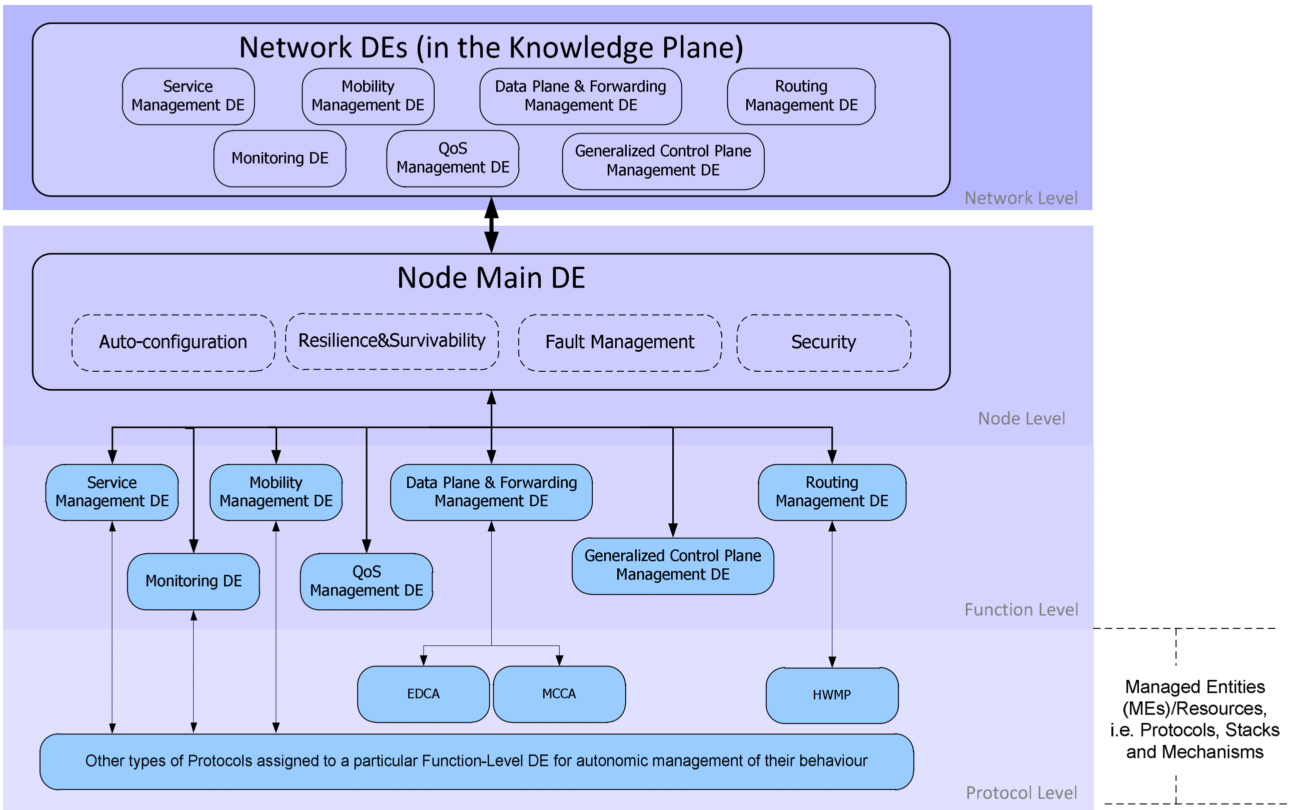
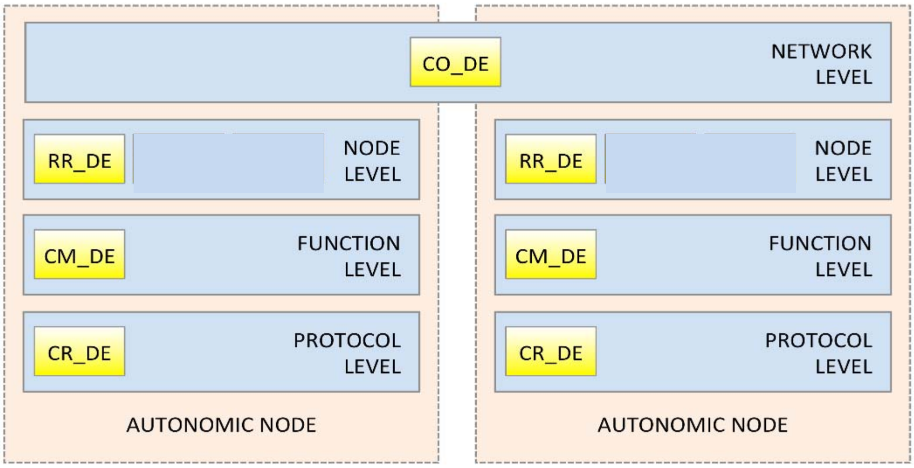


Figure 8: Complementary Views on Block diagram of DEs in autonomicity-enabled Ad-hoc and mesh architecture



NOTE: The DEs indicated may need to be implemented as functionalities of the fundamental GANA DEs that can be mapped to take the roles of the DEs depicted here.

Figure 8a: instantiation case for cooperation and coordination communication scenarios

The GANA Reference Model is abstract and it is described in a technology independent way. Figure 8 illustrates its instantiation onto Ad-hoc and 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 functionalities of selected DEs at the function, node and network GANA levels are presented in Table 1.

Table 1: Specific functionalities of selected DE's for Ad-hoc and mesh mode

GANA Level	DE	Specific mesh functionality
Protocol	Cooperative Relaying	Realisation of physical cooperative transmission between or among Ad-hoc or mesh nodes.
Function	Monitoring	Configures and manages passive and active measurements on the wireless interface. Provides cross-layer measurements to support QoS, routing, forwarding and mobility management functions.
Function	Data Plane & Forwarding Management	Manages the medium access function and node coordination. The medium access function may cover both contention based (e.g. CSMA/CA) and contention free protocols (e.g. polling, TDMA).
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. Provides resilience-aware behaviour through the interaction with the Node Level Resilience and Survivability DE.
Function	Cooperation Management (CM)	Assignment of nodes to Virtual Cooperative Sets and the relevant instantiation of Distributed Spatio-Temporal Block Coding [i.12].
Node	Auto configuration	Manages neighbourhood discovery, secure peer establishment, addressing, channel management, topology management, fetching of Configuration Profiles and Policies specified by the Operator.
Node	Re-Routing (RR-DE) See note	Re-routing to data packets in a possibly cooperative manner to address any changes in network topology resulting from the dynamism of the Ad-hoc mode or a simple failure in the mesh one.
Node	Fault Management	Primarily supporting Re-Routing and interacting with Resilience and Survivability to accommodate any imminent failures.
Node	Resilience and Survivability	Primarily supporting Re-Routing and interacting with Fault Management to accommodate any imminent failures.
Network	Monitoring	Analyses/learns/reasons on long term data measurements (e.g. link stability for correct routing decisions, proper channel management to avoid interferences with other networks/systems).
Network	Data Plane & Forwarding Management	Realizes slower control loop, when wider global knowledge is required in addressing the problems affecting the forwarding behaviour.
Network	Generalized Control Plane Management	Manages control plane protocols and mechanisms.

GANA Level	DE	Specific mesh functionality
Network	Routing Management	Optimizes flow capacity, number of hops, link reliability, provides network-wide address planning, topology management, channel planning.
Network	Cooperation Orchestration	Orchestration of Autonomic Cooperative Behaviour between/among Ad-hoc or mesh nodes from the global network perspective.
NOTE:	This DE should be merged into the Routing Management DE at Function Level rather and not considered as a Node-Level DE.	

NOTE: Some New DEs (outside of those fundamentally defined by the GANA) have been defined in the present document for this specific use case, but a further study of how to merge the functionalities of these newly defined DEs into the appropriate GANA fundamentally defined DEs should help complete the merging process for the DEs in question (see Figure 8a).

The further study should consider that the RR-DE, CR-DE could be merged into the closely related DE in Figure 8, namely the Function-Level Routing Management DE, particularly if the Managed Entities (MEs) of the RR-DE and CR-DE are all associated with routing aspects (protocols and mechanisms). Also if the CM-DE is deemed as managing and controlling MEs that are linked to routing aspects, the CM-DE can be merged into a functionality of the Function-Level Routing Management DE, and if the aspects managed and controlled by the CM-DE are of routing and forwarding in nature, its intended functionality can be split and implemented as functionalities of the Function-Level Routing Management DE and the Function-Level Data Plane & Forwarding Management.

Such a study needs to be fully completed for a properly done GANA instantiation. The further study would need to consider that the Cooperative Relaying Management DE that dynamically manages and adapts MPR (OLSR), the Cooperation Management DE that dynamically manages and adapts DSTBC behaviour, and the Re-Routing Management DE, can be merged into the overall implementation of the Function-Level Routing Management DE as discussed above. Also a Cooperation Orchestration DE on the network level could be considered and could be simply be realized as part of the overall functionality of the Network Level Auto-Configuration DE, but a discussion on this subject would need to be conducted to identify the best approach.

There are four characteristic mesh DEs defined at the GANA Function-Level:

- monitoring;
- data plane & forwarding management;
- generalized control plane management;
- 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 or MCCA as defined in IEEE 802.11 [i.8]) 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.

One of the most important Node-Level DEs for a mesh network is responsible for self-configuration. It realizes a number of management functions such as addressing, channel management, neighbourhood discovery, peer establishment, and topology management. These functions can also support other self-management methods. Another four DEs (their names are the same as for DEs enumerated at the GANA Function-Level) 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, that can help routing protocols avoid using unstable mesh links.

- The data plane & forwarding management DE requires global knowledge about the network behaviour 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 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.

In particular, starting from the protocol level, there is a modified Cooperative Relaying Decision Element CR DE deployed which is responsible for the interactions with the routines of the network layer protocol taking care of the integration of cooperative relaying into a control data dissemination mechanism such as, for example, the Multi-Point Relay (MPR) selection heuristics of the Optimised Link State Routing (OLSR) protocol. However, following the GANA assumption related to protocol simplicity, certain logic is purposely elevated to the function level, where the Cooperation Management Decision Element CM DE resides. The main responsibility of CM DE is to instantiate the process of routing information enhanced cooperative relaying consisting in assigning Ad-hoc or mesh nodes to Virtual Cooperative Sets (VCS) and, thus, instantiating Distributed Spatio-Temporal Block Coding (DSTBC).

Moving up the GANA abstraction levels, the node level contributes with the inclusion of the so necessary resilience and dependability through the introduction of the Re-Routing Decision Element CR DE, Fault Management FM DE, and Resilience and Survivability RS DE. In fact, the CR DE, having access to the RS DE and FM DE, both being able to jointly control the symptoms suggesting that a failure may be imminent and reacting appropriately, may trigger the relevant, possibly cooperative, re-routing procedure well in advance and, thus, guarantee service continuity.

Last but not least is the new Cooperation Orchestration Decision Element CO DE being responsible for overseeing the overall process of autonomic cooperation from the highest, network layer perspective (e.g. IEEE 802.11s [i.8]) [i.12] and [i.14] (Figure 8a).

5.3 Parameter and Functionality Mapping

There exists a strong relationship between the mesh node type (Section 2) and the supported Function Level DEs. Table 2 presents a mapping between these DEs and the mesh node types. Certain Function Level DEs are critical for every mesh node type:

- Service Management;
- Monitoring;
- QoS Management;
- DP&F Management;
- GCP Management.

The Routing Management DE is crucial for the mesh core network which means that it should be instantiated in MGWs and MRNs. Alternatively, the Mobility Management DE, which deals with the handovers of user terminals, can be instantiated only by MANs.

For addressing the stability and coordination of DEs, the GANA Reference Model includes techniques and architectural principles that ensure that control-loops can be designed in a way that guarantees non-coupling and/or non-conflicting behaviours of the DEs. Following these principles (in particular, the concept of DE ownership of an ME or its parameters), a DE-to-ME parameter mapping table is required for each instantiation of the reference model onto the target architecture. For all the MEs and parameters of the resources available at a node, this table should provide a one-to-one mapping of a particular configurable and controllable parameter of an ME to a single DE. Table 3 contains example mappings of Function Level DEs to parameters of three protocols defined by IEEE 802.11 [i.8] for mesh networks:

a) Enhanced Distributed Channel Access (EDCA);

b) MCF (Mesh Coordination Function) Controlled Channel Access (MCCA); and

c) Hybrid Wireless Mesh Protocol (HWMP).

Table 2: A mapping between the mesh node types and the Function Level DEs

Mesh Gateway	Mesh Node	Mesh Access Node
Service Management	Service Management	Service Management
Monitoring	Monitoring	Monitoring
QoS Management	QoS Management	Mobility Management
DP&F Management	DP&F Management	QoS Management
GCP Management	GCP Management	DP&F Management
Routing Management	Routing Management	GCP Management

Table 3: DE-to-ME parameter mapping table

Parameter mapping	Function Level DE	ME (protocol)	Example parameter
Case 1: (preferred mapping): an ME is fully assigned to a single DE	DP&F Management DE	MCCA	Maximum fraction of time allowed for MCCA operation (Mesh Access Fraction)
	Routing Management DE	HWMP	Maximum number of retries for path request (PREQ) messages
Case 2: an ME partitioned such that varying parameter sets are assigned to different DEs	DP&F Management DE	EDCA	RTS/CTS threshold
	QoS Management DE	EDCA	Minimum contention window size for a given Access Category

5.4 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) [i.7]. MBTS forms an intermediation layer between the KP and the network elements. The MBTS translates commands (responses) from (to) the Network-Level-DEs into (from) 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 and find mechanisms that should 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 GANA DEs. In the literature there are various scenarios and business cases for the deployment and the maintenance of Ad-hoc and 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 network, affecting the deployment strategy for the KP. Two paradigms have been identified for the instantiation of the KP to networks, namely centralized KP and overlay KP [i.4].

Centralized KP is instantiated as a separate functional block that it is placed outside the network area (Figure 9). This functional block has a global view of the network, coordinating its functions that is owned and controlled by a specific actor, e.g. network operator.

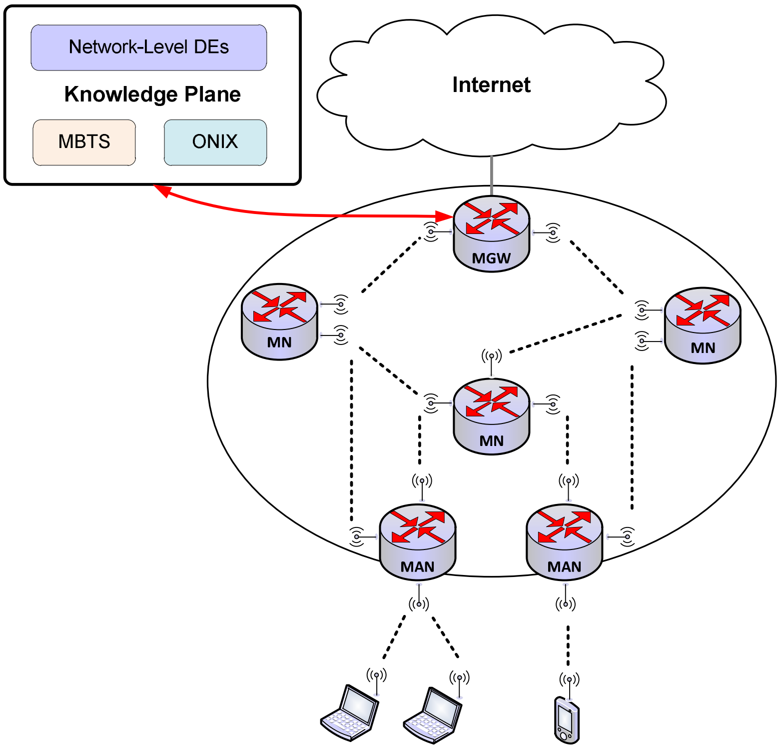


Figure 9: Centralized Knowledge Plane [to be generalized]

In the centralized case, the KP is hosted in a predefined position; hence the discovery phase is mainly driven by the Mesh Gateway (MGW) node. The MGW keeps the address of the KP, which is provided to the rest of the nodes of the mesh network after their request. In addition, the MGW provides the KP address to a newly deployed mesh node after it joins the network.

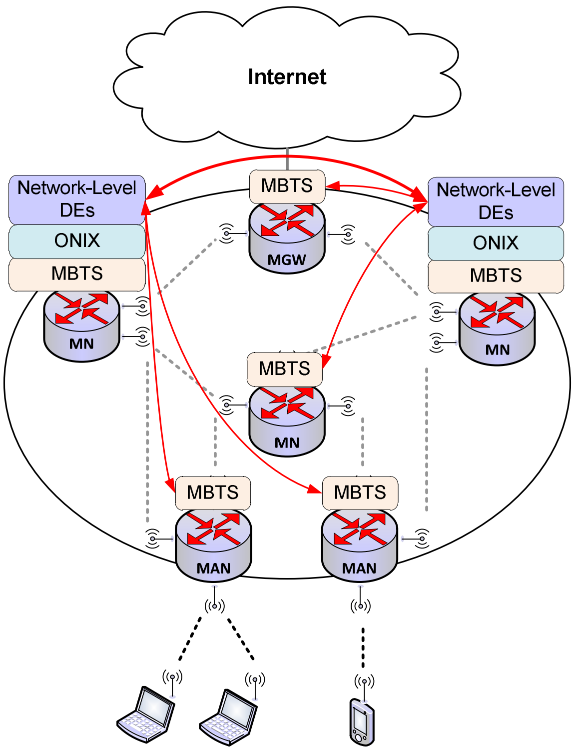


Figure 10: Overlay Knowledge Plane in a mesh network

Overlay KP is deployed in a distributed manner inside the mesh network nodes (Figure 10). This type of KP is selected for the case where a separate/standalone KP is not available or accessible. This overlay KP analyses the behaviours of the network and provides collaboration knowledge to nodes to control the network with same goal, e.g. optimization, self-healing, since it has the role of the NMS. 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;

b) the KP discovery by the simple nodes.

The type of mesh nodes or even the expected life time of the mesh network are among the criteria that could drive the instantiation of the overlay and the GANA Network-Level-DEs that meet the goal identified 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 GANA, 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 cases for KP deployment the terminals are used as monitoring points, which periodically shared situated view from monitoring data (e.g. capabilities description, configuration data, events, alarms, measurements) to the KP.

NOTE: The aspects described in this section, concerning wireless mesh network architecture can be further generalised to encompass the Ad-hoc mode.

5.5 Instantiation of Reference Points

The GANA Reference Model defines Reference Points (Rfps) between DEs as well as between DEs and other Functional Blocks (FBs). An Rfp is a logical interface between at least two FBs, over which characteristic information is exchanged (Figure 11). This includes messages and data that characterizes what is communicated between the FBs.

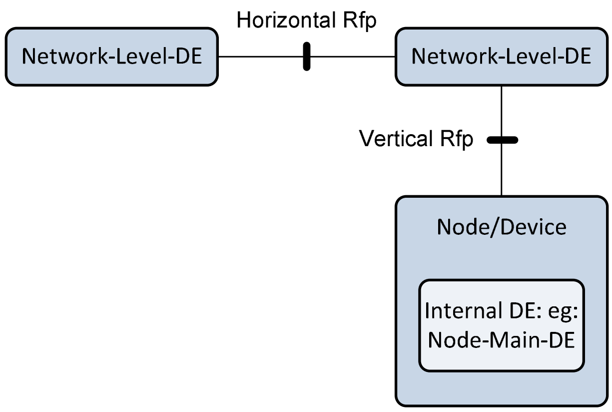


Figure 11: Example of VRP and HRP

Since the definition of Rfps within the GANA model is general, their instantiation for mesh networks should 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 Ad-hoc and 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 (Figure 11). The second case can be applicable to, e.g. coordination of a relevant Ad-hoc or mesh network composed of coexisting and/or collaborating regional zones, for which communication between DEs at the corresponding level is required, not within the devices themselves but over the very autonomic network.

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 [i.20] or SNMP are taken into account as well. For enhanced flexibility the MBTS service can be used in the Rfps implementations.

5.6 Scenarios and Implications on Governance and Behaviours

The flexibility of the GANA mesh network should allow different use cases to setup the relevant Ad-hoc and/or mesh network according to the different players involved in this network, as well as the heterogeneous technology used to provide the connectivity [i.9] and [i.10]. The GANA governance mechanism allows the knowing of how such a network should be setup with common objectives. This implies that the administrative authority provisioning that the network is also provisioning a Knowledge Plane that covers the scope of this Ad-hoc or mesh network. Furthermore, as the GANA Ad-hoc or mesh network could interact with legacy infrastructure such as fixed or wireless networks the GANA Ad-hoc or mesh network should share is behaviour with such network which could provide Internet connectivity.

The Ad-hoc and/or mesh network could be used to extend the coverage or the capacity of a small area network, such as a home area network or a football stadium. In this case such a network will be managed and secured not only by the provider but also by the owner of the small area which provides the gateway to Internet. 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 network is provisioned and owned by the Internet provider. The network should be then governed according to the different players involved its activation. The players determine who would own and provision the KP.

The Ad-hoc and/or mesh network could also be used to provide a freedom 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 Ad-hoc and/or mesh network itself would have to self-organize and instantiate a "minimal" Knowledge Plane and its Functional Blocks (such as the ONIX distributed peer to peer servers) in order to function without any explicit or with minimal governance. Such a network could also provide democratic activists a secure and reliable platform to ensure their communications cannot be controlled or cut off by authoritarian regimes. Finally, the Ad-hoc and/or mesh network could also be used to connect heterogeneous nodes supporting various network technologies (Bluetooth®, Wi-Fi®, Ethernet, 2/3/4G, NFC, RFID) [i.11]. In this case it is necessary to understand how capabilities of individual devices are used to compose a network. According to [i.7], every autonomic node should 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 vehicular, mobile, Ad-hoc network.

History

Document history		
V1.1.1	February 2017	Publication