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Core Network and Interoperability Testing (INT/WG AFI); Federated GANA Knowledge Planes (KPs) for Multi-Domain Autonomic Management & Control (AMC) of Slices in the NGMN® 5G End-to-End Architecture Framework

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Contents

Intellectual Property Rights 5
Foreword 5
Modal verbs terminology 5
Introduction 5
1 Scope 6
2 References 6
2.1 Normative references 6
2.2 Informative references 6
3 Definition of terms, symbols and abbreviations 9
3.1 Terms 9
3.2 Symbols 9
3.3 Abbreviations 9
4 Principles for Autonomic Networking and Autonomic Management & Control (AMC), and Enablers 11
4.1 Overview on Autonomics Principles and Enablers for Autonomic Networking, Autonomic Management & Control (AMC), and Autonomous Networks 11
4.2 Closed Control-Loop(s) 13
4.3 Introduction to the ETSI GANA Reference Model for Autonomic Networking, Cognitive Networking and Self-Management 14
4.4 Federation of GANA Knowledge Planes Framework 22
4.5 AMC Requirements in the NGMN® 5G E2E Architecture, and need for Knowledge Plane Federations for E2E AMC in NGMN® E2E 5G Architecture 23
4.6 The Value of Autonomics in Network Slicing 24
5 SliceNet Architecture 25
5.1 Overview 25
5.2 Control Framework 26
5.3 Cognitive management 28
5.3.0 Introduction 28
5.3.1 Cognitive Control Loop 29
5.3.2 Knowledge & Monitoring 30
5.3.3 Analysis 30
5.3.4 Planning & Execution 33
5.4 Slice management 35
5.5 Orchestration 36
6 Impact of MEC, Network Slicing and Hardware Acceleration to the SliceNet Concepts and Principles 37
6.1 Impact of Virtualization 37
6.2 Impact of MEC 38
6.3 Impact of Network Slicing 39
6.4 Impact of Hardware Acceleration 40
7 GANA in ETSI 5G PoC Implementations by the Industry 41
8 Mapping of SliceNet architecture components to GANA Concepts and Architectural Principles, How to use the SliceNet components to implement GANA Components 52
8.1 General Mapping of SliceNet Architectural Concepts and Principles to GANA Concepts and Principles 52
8.2 Autonomic networks and General GANA integration with SDN, NFV, Data Analytics Applications, Orchestrators, and Other Management and Control Systems 53
8.3 SliceNet mapping to GANA Network Level (Knowledge Plane (KP) Level) Autonomics 55
8.4 How to implement a GANA Knowledge Plane (KP) for a specific network segment using the SliceNet Intelligence Framework 56
9 Addressing the AMC Requirements in the NGMN® 5G E2E Architecture 57

10 Conclusion..58

Annex A: Bibliography 60

History..61

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Core Network and Interoperability Testing (INT).

Modal verbs terminology

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Introduction

The present document provides a mapping and evaluation of architectural components for autonomic network management & control developed/implemented in the EU-funded SliceNet Project to the ETSI AFI Generic Autonomic Networking Architecture (GANA) model - an architectural reference model for autonomic networking, cognitive networking and self-management. It serves to provide useful insights to implementers of ETSI GANA Knowledge Plane (KP) Platforms on approaches that can be taken in implementing ETSI GANA Knowledge Plane Platforms and how to federate them for E2E (Cross-Domain) Autonomic Management and Control (AMC) operations across network segments such as Radio Access Networks (RANs), Transport Networks and Core Networks. It goes further to discuss how to address the AMC Requirements specified in NGMN® E2E 5G Architecture by a way of providing insights on how ETSI GANA KP platforms in an E2E 5G Architecture can address the AMC requirements, while leveraging experiences gained in SliceNet Project in implementing GANA autonomic/cognitive management and control software components for 5G network slices.

1 Scope

The present document presents a plausible approach to implementing Federated GANA Knowledge Planes (KPs) Platforms for E2E Multi-Domain Federated Autonomic Management and Control (AMC) of 5G Network Slices in NGMN® E2E 5G Architecture, using components prototyped and implemented in the European Union (EU) funded SliceNet Project (Grant Agreement N° 761913). The present document produces and leverages a mapping of architectural components for autonomic network management & control developed/implemented SliceNet Project to the ETSI TC INT AFI Generic Autonomic Networking Architecture (GANA) model - an architectural reference model for autonomic networking, cognitive networking and self-management. The mapping identifies the components that were prototyped in Slicenet Project that can be used to implement specific GANA Functional Blocks (FBs) for Autonomics and their associated Reference Points (Rfps), while providing the illustrations that help implementers of GANA autonomics in 5G networks. Other aspects covered in the present document are:

- A Study of GANA aligned AMC Requirements in the NGMN® 5G E2E Architecture in order to provide answers on how the approach presented in the present document can help implementers of GANA AMC solutions for 5G.
- Providing useful insights to implementers of ETSI GANA Knowledge Plane (KP) Platforms on approaches that can be taken in implementing ETSI GANA Knowledge Plane Platforms and how to federate them for E2E (Cross-Domain) Autonomic Management and Control (AMC) operations across network segments such as Radio Access Networks (RANs), Transport Networks and Core Networks.
- Providing insights on leveraging experiences gained in SliceNet Project in implementing GANA autonomic/cognitive management and control software components for 5G network slices.

The mapping of the components to the GANA model concepts serves to illustrate how to implement the key abstraction levels for autonomics (self-management functionality) in the GANA model for the targeted wireless networks context, taking into consideration the work done in ETSI TR 103 495 [i.26].

It also shows how GANA can be implemented using the components developed in SliceNet project as an example.

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.

[i.1] ETSI White Paper No.16 GANA: "Generic Autonomic Networking Architecture Reference Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services".

NOTE: Available at http://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp16_gana_Ed1_20161011.pdf.

[i.2] ETSI TS 103 195-2 (V1.1.1): "Autonomic network engineering for the self-managing Future Internet (AFI); Generic Autonomic Network Architecture; Part 2: An Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management".

NOTE: Available at https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=50970.

[i.3] ETSI 5G PoC on 5G Network Slices Creation, Autonomic & Cognitive Management & E2E Orchestration-with Closed-Loop (Autonomic) Service Assurance for the IoT (Smart Insurance) Use Case.

NOTE: More information at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals.

[i.4] White Paper No.1 of the ETSI 5G PoC: "C-SON Evolution for 5G, Hybrid SON Mappings to the ETSI GANA Model, and achieving E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices by Cross-Domain Federated GANA Knowledge Planes".

NOTE: More information at https://intwiki.etsi.org/images/ETSI_GANA_in_5G_PoC_White_Paper_No_1_v1.28.pdf.

[i.5] ETSI TR 103 473 (V1.1.2): "Evolution of management towards Autonomic Future Internet (AFI); Autonomicity and Self-Management in the Broadband Forum (BBF) Architectures".

NOTE: Available at https://www.etsi.org/deliver/etsi_tr/103400_103499/103473/01.01.02_60/tr_103473v010102p.pdf.

[i.6] ETSI TR 103 404: "Network Technologies (NTECH); Autonomic network engineering for the self-managing Future Internet (AFI); Autonomicity and Self-Management in the Backhaul and Core network parts of the 3GPP Architecture".

[i.7] ONAP® Open Source Project: "ONAP Architecture Overview".

NOTE 1: Available at https://www.onap.org/.

NOTE 2: Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.

[i.8] BBF CloudCO Open Source Project.

NOTE: Available at https://www.broadband-forum.org/cloudco.

[i.9] OPNFV® Open Source Project.

NOTE 1: Available at https://www.opnfv.org/.

NOTE 2: Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.

[i.10] ONOS Open Source Project.

NOTE: Available at https://onosproject.org/.

[i.11] OpenDayLight® Open Source Project.

NOTE 1: Available at https://www.opendaylight.org/.

NOTE 2: Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.

[i.12] ETSI OSM (Open Source MANO).

NOTE: Available at https://osm.etsi.org/.

[i.13] ACUMOS ®: "An Open Source AI Machine Learning Platform".

NOTE 1: Available at https://www.acumos.org/.

NOTE 2: ACUMOS® is a registered trademark of LF Projects, LLC.

[i.14] White Paper No.3 of the ETSI 5G PoC: "Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring and Feeding of Knowledge into the ETSI GANA Knowledge Plane for Autonomic Service Assurance of 5G Network Slices; and Orchestrated Service Monitoring in NFV/Clouds".

NOTE: Available at ETSI_5G_PoC_White_Paper_No_3_2019_v1.19.pdf.

[i.15] White Paper No.2 of the ETSI 5G PoC: "ONAP Mappings to the ETSI GANA Model; Using ONAP Components to Implement GANA Knowledge Planes and Advancing ONAP for Implementing ETSI GANA Standard's Requirements; and C-SON - ONAP Architecture".

NOTE: Available at ETSI_5G_PoC_White_Paper_No_2_Final_v7.3.pdf.

[i.16] ETSI 5G PoC Report on Specifications of Integration APIs for the ETSI GANA Knowledge Plane Platform with Other Types of Management & Control Systems, and with Info/Data/Event Sources in general.

NOTE: Available at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals.

[i.17] ETSI TS 129 520 (V16.6.0): "5G; 5G System; Network Data Analytics Services; Stage 3 (3GPP TS 29.520 version 16.6.0 Release 16)".

[i.18] ETSI TS 128 533 (V15.0.0): "5G; Management and orchestration; Architecture framework (3GPP TS 28.533 version 15.0.0 Release 15)".

[i.19] 5G End-to-End Architecture Framework by NGMN® Alliance: "P1-Requirements and Architecture: NGMN® 5G E2E Architecture Framework v3.0.8".

NOTE: Available at https://www.ngmn.org/publications/5g-end-to-end-architecture-framework-v3-0-8.html.

[i.20] White Paper No.4 of the ETSI 5G PoC: "ETSI GANA as Multi-Layer Artificial Intelligence (AI) Framework for Implementing AI Models for Autonomic Management & Control (AMC) of Networks and Services; and Intent-Based Networking (IBN) via GANA Knowledge Planes (KPs)".

NOTE: Available at ETSI_5G_PoC_White_Paper_No_4_v3.1.pdf.

[i.21] White Paper No.6 of the ETSI 5G PoC: "Generic Framework for Multi-Domain Federated ETSI GANA Knowledge Planes (KPs) for End-to-End Autonomic (Closed-Loop) Security Management & Control for 5G Slices, Networks/Services".

NOTE: Available at ETSI_5G_PoC_White_Paper_No_6.pdf.

[i.22] 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)".

[i.23] SliceNet Project Deliverable D5.7: "Framework for Cognitive SLA and QoE Slice Management", December 2019.

NOTE: Available at https://doi.org/10.18153/SLIC-761913-D5_7.

[i.24] SliceNet Project Deliverable D5.5: "Modelling, Design and Implementation of QoE Monitoring, Analytics and Vertical-Informed QoE Actuators, Iteration I.

NOTE: Available at https://doi.org/10.18153/SLIC-761913-D5_5.

[i.25] SliceNet Project Deliverable D5.6: "Modelling, Design and Implementation of QoE Monitoring, Analytics and Vertical-Informed QoE Actuators, Iteration II".

NOTE: Available at https://doi.org/10.18153/SLIC-761913-D5_6.

[i.26] ETSI TR 103 495: "Network Technologies (NTECH); Autonomic 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".

[i.27] White Paper No.5: "Artificial Intelligence (AI) in Test Systems, Testing AI Models and ETSI GANA Model's Cognitive Decision Elements (DEs) via a Generic Test Framework for Testing GANA Multi-Layer Autonomics & their AI Algorithms for Closed-Loop Network Automation".

NOTE: Available at ETSI_5G_PoC_White_Paper_No_5.pdf.

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

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

3GPP	3rd Generation Partnership Project
AFI	Autonomic Future Internet
AIOPS	Artificial Intelligence for IT Operations
AMC	Autonomic Management & Control
AMF	Access and Mobility Management Function
AN	Autonomous Network
API	Application Programming Interface
AUSF	AUthentication Server Function
BBF	BroadBand Forum
CN	Core Network
CP	Control Plane
CPS	Control Plane Services
CPSR	Control Plane Service Register
CPU	Central Processing Unit
CRUD	Creation/Configuration, Read, Update and Delete
C-SON	Centralized Self Organizing Network
CSP	Communications Service Provider
DB	DataBase
DDCM	Data-Driven Control and Management
DE	Decision making Element
DP	Data Plane
DSON	Distributed SON
DSP	Digital Service Provider
E2E	End-to-End
EMS	Element Management System
EPC	Evolved Packet Core
EPS	Edge Packet Service
FCAPS	Fault, Configuration, Accounting, Performance, Security
FGE	Forward Graph Enabler
GANA	Generic Autonomic Network Architecture
GW-C	GateWay-Control plane
GW-U	GateWay-User plane
IBN	Intent-Based Networking
ICT	Information and Communications Technology
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
IPC	Inter PoP Connection

ISG	Industry Specification Group
IT	Information Technology
JSON	Java Script Notation Object
KB	Knowledge Base
KP DE	Knowledge Plane Decision-making Element
KP	Knowledge Plane
KPI	Key Performance Indicator
LL-MEC	Low-Latency MEC
MANO	MANagement and Orchestration
MAPE-K	Monitor-Analyze-Plan-Execute over a shared Knowledge
MB	MegaByte
MBTS	Model-Based Translation Service
MDAS	Management Data Analytics Service
MEC	Mobile Edge Computing
ML	Machine Learing
NBI	Northbound interface
NE	Network Element
NF	Network Function
NFV	Network Function Virtualisation
NFVO	NFV Orchestrator
NGMN®	Next Generation Mobile Networks
NMR-O	NFV MEC RAN Orchestrator
NRF	Network Repository Function
NS	Network Slice
NSO	Network Service Orchestrator
NSP	Network Service Provider
NSS	Network Sub-Slice
NSSF	Network Slice Selection Function
NSST	Network Slice Subnet Templates
NST	etwork Slice Template
NWDAF	Network Data Analytics Function
OAI	OpenAirInterface
ONAP	Open Network Automation Platform
ONIX	Overlay Network for Information eXchange
OOB	Out-Of-Band
OODA	Observe-Orient-Decide-ACT
OSA	One Stop API
OSM	Open Source MANO
OSS	Operations Support Systems
OVS	Open Virtual Switch
P&P	Plug & Play
PAP	Policy Administration Point
PCF	Policy Control Function
PCI	Policy Catalogue & Inventory
PCM	Policy Control Manager
PCS	Proactive Control Scheme
PDP	Policy Decision Point
PF	Policy Framework
PGW	Packet Gateway
PNF	Physical Network Function
PR	Policy Recommender
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
REST	Representational State Transfer
RNIS	Radio Network Information Service
SBA	Service Based Architecture
SBI	Service Based Interface
SDK	Software Development Kit
SDN	Software Defined Networks
SDO	Standards Development Organizations
SGW	Serving GateWay

SLA	Service Level Agreement
SMF	Session Management Function
SNMP	Simple Network Management Protocol
SON	Self Organizing Networks
SS-O	Service and Slice Orchestrator
TAL	Tactical Autonomic Language
TCAM	Ternary Content Addressable Memories
UDM	Unified Data Management
UE	User Equipment
UI	User Interface
UP	User Plane
UPF	User Plane Function
VIM	Virtual Infrastructure Management
VLAN	Virtual LAN
VNF	Virtual Network Function
WAN	Wide Area Network
WG	Working Group
WIM	WAN Infrastructure Manager

4 Principles for Autonomic Networking and Autonomic Management & Control (AMC), and Enablers

4.1 Overview on Autonomics Principles and Enablers for Autonomic Networking, Autonomic Management & Control (AMC), and Autonomous Networks

Autonomic systems rely on an autonomic elements which regularly sense the possible sources of change through sensors, reason about the current situation and arrange adaptations through actuators. Autonomous networks focuses on the definition of closed loops (MAPE-K, OODA, cognitive loop, etc.) or controllers as enablers for autonomy in future networks. The Autonomous Networks aims to define fully automated innovative network and services for vertical industries' users and consumers, supporting self-configuration, self-healing, self-optimizing and self-evolving network infrastructures. Autonomous Networks incorporate a simplified network architecture, autonomous domains and automated intelligent business/network operations for the closed control loop, offering the best-possible user experience, full lifecycle operations automation/autonomy and maximum resource utilization. One of the Key inseparable features of an autonomic system is a need of continuous monitoring.

Self-manageability in GANA is achieved through instrumenting the network with autonomic Decision-making-Elements (DEs), which automate network operations by implementing control loops. Such control loops operate using the knowledge regarding events and the state of network resources.

The GANA model defines a generic Autonomic Management and Control (AMC) framework and structure within which to specify and design autonomics-enabling functional blocks for any network architecture and its management architecture. Autonomic Management & Control is about Decision making elements (Des) as autonomic functions with cognition introduced in control and management plane. Cognition is seen as learning and reasoning used to effect advanced adaptation in Decision making Elements. Control is about control-logic as the core of DE that realizes a control-loop in order to adjust network resources/parameters or services. From an architecture perspective, AMC Framework and 3GPP Hybrid-SON (Self Organizing Network) model are compatible with each other. Both shares common design principles on enabling implementers of autonomics algorithms to combine centralized and distributed control of network resources, parameters and services. Federation of AMC allows knowledge exchanging, sharing, interaction and collaboration among KPs with each KP platform governing and controlling the behaviour of an autonomic system.

The following concepts and paradigms help implementers of ETSI GANA autonomics in understanding important taxonomy of terms and concepts that related in this area of the drive to smart and self-driving networks:

- **Autonomic Network (AcN)--concept:** An Autonomic Network either refers to the Network Infrastructure made up of Network Elements/Functions (NEs/NFs) that exhibit autonomics (control-loops) in their behaviors, or is the inclusion together of Network Infrastructure with some level of autonomics (control-loops) in NEs/NFs and its associated Management and Control architecture that also exhibits autonomics (Control-Loops) at that higher level. A Multi-Layer AcN's property of being "autonomic" (also called "**autonomicity**" (a paradigm) in ETSI Standards such as [i.2]), relates to **Hierarchical (nested) and Interworking Control-Loops introduced at various Abstraction Levels (from NE/NF level) up into the Management & Control Systems Level of the Network**.

NOTE: On the journey to implementing an Autonomous Network (AN) with certain degree of autonomy, the starting point is designing the network as an Autonomic Network (AcN) as the foundation. The science of Control-Loops (called "**Autonomics**") is key enabler for achieving the property of being autonomous, and that an AcN is expected to evolutionarily "maximize" the property of being "autonomous" in as far as the "**Degree and Measure of Operations Tasks that can be performed by the autonomic network (AN) without direct human involvement in the decision and actions**".

- **An Autonomous Network (AN)--concept: An AN is a network that exhibits a property called Degree of Autonomy that** pertains to the Degree and Measure of Operations Tasks that can be performed by an Autonomic Network (AcN) without direct human involvement in the decision and actions, thanks to Autonomics (the science of Control-Loops) in-built in the AcN as the enablers for the autonomous behavior (an operational property of the autonomic network). The Degree of Autonomy is associated with Maturity Levels for Autonomy that are increasingly attained by the Autonomic Network (AcN) over time, thanks to the Evolution of the Autonomics (Control-Loops) by enrichment of automation in network and services management and control intelligence in the Control-Loops to maximize the autonomic network's property of being Autonomous. In ICT networks, AN is to be governable by Human Operator through inputs such as business goals and policies and other governance inputs such an Intents, Service Level Agreements (SLAs) for services to be delivered by the AN.

- **Automated Management (a paradigm):** It is about **workflow reduction and automation** i.e. **automation of the processes** involved in the creation of network and/or service configuration inputs using specialized task **automation tools (e.g. scripts, automated workflow management tools, network planning tools, policy generators for conflict-free policies, intents, goals, Service Level Agreement (SLAs), etc.)** such that the Inputs can be provided by the Human Operator to the Autonomic Network (AcN) or Autonomous Network (AN) to govern its operation. The Inputs (high-level inputs), also called Governance Objectives/Goals for the AcN/AN are further operated upon by the AcN/AN to further derive detailed low-level configuration data and actions that are then applied by the AcN/AN on its own to self-configure and execute other self-* operations such as self-optimization, self-diagnosis, self-repairing/healing, self-protection during its operation. The AcN/AN exposes an interface called the **Governance Interface** through which the **Automated Management realm** provides the Governance Inputs (Objectives/Goals) to the AcN/AN. The same Governance Interface of the AcN/AN is used by the AcN/AN to provide feedback to the Human (through Tools of the Automated Management realm) in form of Reports that provide insights such as how the AcN/AN is fairing in fulfilling the Objectives, or feedback in form escalations that the AcN/AN would like the Human Operator to get involved in the decisions on how to handle certain situations the AcN/AN has encountered.

- **Autonomic Management and Control (AMC) -a paradigm:** It emphasizes **learning, reasoning, and adaptation** using control-loops that also take into consideration the feedback knowledge obtained from network and services monitoring**. Automated Management** provides Input (Governance Inputs) to the Autonomic Management & Control (AMC) of Networks and Services Domain ("area/space"). [i.1] and [i.2] define the AMC paradigm as the interworking of nested and hierarchical control-loops and associated logics introduced in the Management Plane, in the Control Plane, and also in the converged (non-disaggregated) Management Planes and Control Planes (as there are such cases). Indeed, Autonomic Management & Control should exhibit a network Governance Interface through which the input that governs the configuration of an Autonomic Network (AcN) should be provided by the human operator. Thanks to automation tools and mechanisms (Automated Management), by using a high-level language, the operator can define the features of the network services that should be provided by the underlying network infrastructure. Such a business language that can help the operator express high level business goals required of the network may be modelled by the use of an ontology to add semantics and enable machine reasoning on the goals. The human operator defined features relate to business goals, technical goals and some input configuration data that an autonomic network is supposed to use as operational targets (which may flexibly be changed or modified by the operator at any time) for network resources and parameters configurations.

- In the relationship of the two properties of an AcN/AN (of being "autonomic" and being "autonomous"), one can realize that the science of Control-Loops (called "**Autonomics**") is key enabler for achieving the property of being autonomous, and that an AcN is expected to evolutionarily "maximize" the property of being "autonomous" in as far as the "**Degree and Measure of Operations Tasks that can be performed by the Autonomic Network (AcN) without direct human involvement in the decision and actions**". That means that evolving the Autonomics (Control-Loops) of the AcN by enrichment of automation in management, control and associated intelligence in the Control-Loops, **Maximizes** the AcN's property of being Autonomous (but while still remaining governable and controllable by humans-particularly for telecommunication and IT networks meant to serve business customers of network providers). Two Dimensions for Autonomics Evolution of the AcN are:

  1) Market Place Driven Evolution of Decision-making-Elements (DEs) for Autonomics enables onboarding better DEs with better Algorithms;

  2) Algorithmic Evolution of DEs' AI Algorithms for Autonomics.

  The "evolution" takes different paces in deployed AcNs of various organizations. Therefore, **Evolutionary Autonomic Networks** are characterized by the ability to **evolve in maximization of the property of being "Autonomous" (degree of Autonomy** in operations tasks**)** by enriched automation using Control-Loops, to reach an extent by which the human operators see themselves focused mainly on providing Governance Inputs (such as Business Objectives, SLAs, Goals, Policies and Intents) to the Network while experiencing a drastic reduction of involvement in any burdens involving tasks such as security management/control, fault-management and Network Optimization processes for the network (thanks to autonomics features such as self-repair, self-healing, self-protection and self-optimization, self-awareness, by the network on its own).

For more details on taxonomy harmonization in this space and enablers for the paradigms, the following sources provide useful insights [i.20], [i.1] and [i.2].

4.2 Closed Control-Loop(s)

Traditional networks based on human labour-intensive, time and resource-consuming management tasks, carried out by operations teams, should be conducted autonomously by following a much more efficient, intelligent and automated machine-oriented approach. Network transformation and the evolution from the traditional communications industry to the digital services industry demands a paradigm shift in the way networks are planned, deployed and operated.

The evolution to the digital services industry imposes additional challenges on the agility, flexibility and robustness needed to manage the lifecycle of services and underlying resources. In the digital services industry, service innovation cycles are becoming much shorter, service activation is expected to be instantaneous, and services are supposed to be always available and highly responsive. Due to these requirements, the digital services industry is incompatible with human dependencies on service activation, optimization and recovery situations.

The ongoing network transformation towards Network Functions Virtualisation (NFV) and Software-Defined Networks (SDNs) is becoming a reality and will result in a significantly improve in agility, flexibility and cost efficiency to manage network functions, which are the foundations to trigger a paradigm shift in the way network operations are planned, deployed and managed, called cognitive network management. This approach consists of implementing machine-based intelligence to support the creation of autonomous processes to manage complex networking scenarios.

One of the main impacts of this paradigm is the significant reduction of operational costs. Proactive and reactive actions are automated to resolve or mitigate networking problems, thereby minimizing the human effort in maintenance and troubleshooting tasks, and leading to significant Operational Expenditure (OPEX) reduction.

Three key capabilities is to be provided to create a **closed control loop solution** able to support the implementation of autonomous and intelligent cognitive processes:

- **Automated network monitoring:** the key challenge is to build transversal and automated monitoring capabilities crossing all network domains. These can be achieved through the automated deployment of virtualized probes in the network infrastructure to facilitate system-wide distributed monitoring. Collected information has to feed data analysis algorithms, like data analytics, data mining or Machine Learning (ML), in order to create key indicators that may translate to:

    1) service affecting conditions (e.g. network failures, performance bottlenecks, security breaches, intrusions);

    2) conditions that may evolve to service affecting issues in the future;

    3) non-optimal service delivery to specific users, i.e., detection of cases where the service topology being used to deliver a service to end users can be optimized in order to minimize allocated resources or the service QoS.

- **Cognitive framework:** the ability to define high level tactical corrective and preventive measures to respond to the diagnosed conditions. Tactical measures may correspond to reactive actions to fix or mitigate existing network issues or may correspond to proactive actions to prevent the evolution of the diagnosed condition to an effective service-affecting anomaly. These actions typically correspond to services and/or network functions lifecycle management requests (e.g. automated instantiation, configuration, scalability, reconfiguration of connectivity logical topology, etc.).

- **Automated and dynamic service provisioning:** automated and intelligent processes to manage the lifecycle of services and network functions. These comprise the dynamic selection of the best locations and resources for services deployment (or migration) considering the requirements associated with the specific service instance being provisioned (for instance the contracted QoS). This process also includes the provisioning of the key performance indicators to be produced for the service instance.

4.3 Introduction to the ETSI GANA Reference Model for Autonomic Networking, Cognitive Networking and Self-Management

This clause introduces the ETSI GANA Reference Model to provide a basis for the objectives described in the scope of the present document.

The ETSI Generic Autonomic Networking Architecture (GANA) Reference Model is an Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services standardized by ETSI [i.1], [i.2], [i.22], which defines a generic Functional Blocks (FBs), their associated reference points, and messages passed through those reference points. Figure 1 presents the snapshot of the ETSI GANA Reference Model and the aspect of Multi-Layer Autonomics' Cognitive Algorithms for Artificial Intelligence (AI) and the levels of abstractions of self-management functionality. Self-management functionality is a logic (component) that implements a control-loop as the core driver of the self-management behavior in terms of orchestration and/or (re)-configuration of entities that need to be orchestrated, managed and dynamically (re)-configured by the logic to meet certain objectives.

GANA Knowledge Plane (KP) is an Intelligent Management and Control Functional Block which is an integral part of AMC. KP consists of multiple DEs.

Looking more closely at Figure 1, the KP level autonomics is considered as the "Macro-level" autonomics (control-loops for dynamic adaptation of behavior and state), while autonomics introduced in the Network Elements/Functions (NEs/NFs) is considered as "Micro-level" autonomics.

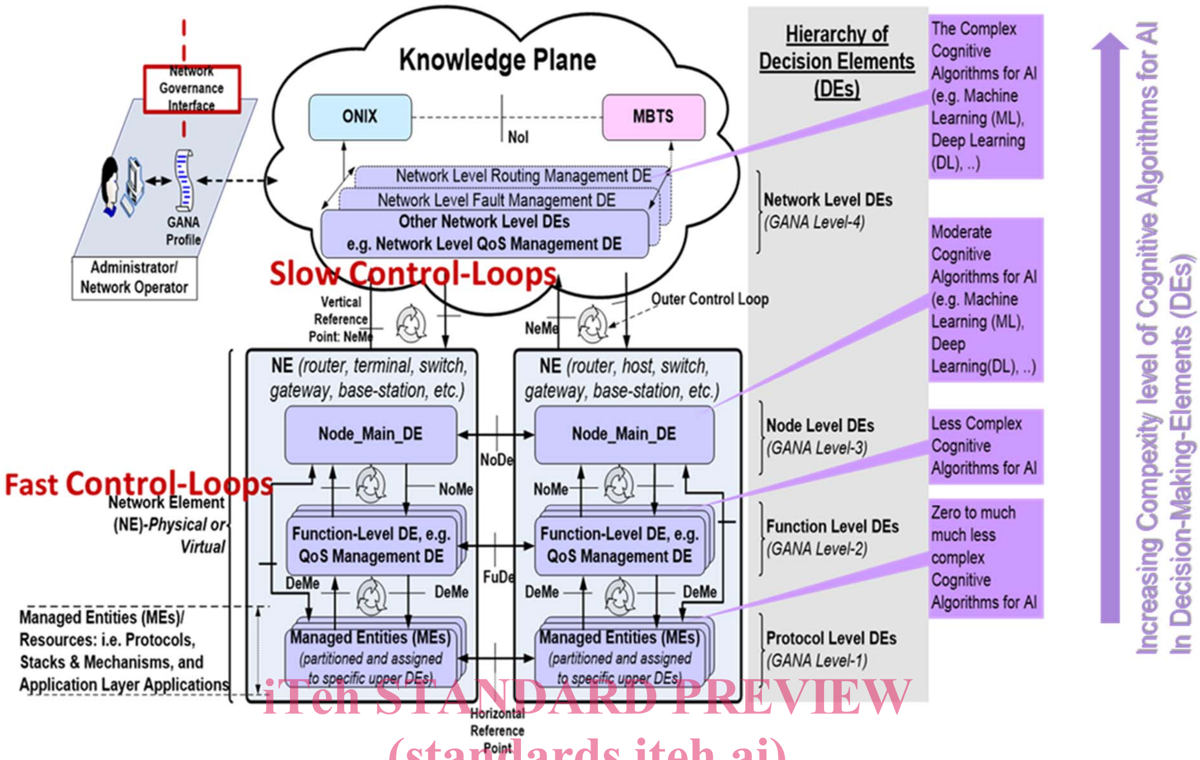

Figure 1: Snapshot of the GANA Reference Model and Autonomics Cognitive Algorithms for Artificial Intelligence (AI), and illustration of the notion of increasingly varying complexity of AI from within an NE up into the Knowledge Plane level

The three key Functional Blocks of the GANA KP are summarized below (in reference to Figure 1):

- **GANA Network-Level DEs:** Decision-making-Elements (DEs) whose scope of input is network wide in implementing "slower control-loops" that perform policy control of lower level GANA DEs (for fast control-loops) instantiated in network nodes/elements. The Network Level DE are meant to be designed to operate the outer closed control loops on the basis of network wide views or state as input to the DEs' algorithms and logics for Autonomic Management and Control (AMC) (the "Macro-Level" autonomics). The Network-Level-DEs (Knowledge Plane DEs) can designed to run as a "micro service".

- **ONIX (Overlay Network for Information eXchange):** is a distributed scalable overlay system of federated information servers). The ONIX is useful for enabling auto-discovery of information/resources of an autonomic network via "publish/subscribe/query and find" mechanisms. DEs can make use of ONIX to discover information/context and entities (e.g. other DEs) in the network to enhance their decision making capability. The ONIX itself does not have network management and control decision logic (as DEs are the ones that exhibit decision logic for Autonomic Management and Control (AMC)).

- **MBTS (Model-Based Translation Service):** which is an intermediation layer between the GANA KP DEs and the NEs ((Network Elements)-physical or virtual)) for translating technology specific and/or vendors' specific raw data onto a common data model for use by network level DEs, based on an accepted and shared information/data model. KP DEs can be programmed to communicate commands to NEs and process NE responses in a language that is agnostic to vendor specific management protocols and technology specific management protocols that can be used to manage NEs and also policy-control their embedded "micro-level" autonomics. The MBTS translates DE commands and NE responses to the appropriate data model and communication methods understood on either side. The value the MBTS brings to network programmability is that it enables KP DEs designers to design DEs to talk a language that is agnostic to vendor specific management protocols, technology specific management protocols, and/or vendor specific data-models that can be used to manage and control NEs.