



**Core Network and Interoperability Testing (INT);
Autonomic/Autonomous IPv6 based 5G Networks:
powered by ETSI GANA Multi-Layer Autonomics &
Multi-Layer AI-Algorithms and IPv6 Capabilities**

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Reference

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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

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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Executive Summary

The main target of the present document is to serve as a Framework or Guide for Implementing Autonomic/Autonomous IPv6 based E2E 5G Networks, by leveraging the ETSI GANA Multi-Layer AI/ML and Multi-Layer Autonomic Management and Control Model and IPv6 Capabilities and its Extensions that enable to Build Autonomic Networks. ETSI GANA is an Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services standardized by ETSI in ETSI TS 103 195-2 [i.2]. Through the Framework, software modules (called Autonomic Functions) for enabling automated management, autonomic management (self-management) and self-adaptive control of the network, called GANA Decision-making-Elements (DEs), and their associated Algorithms (including analytics, optimization and AI/ML algorithms), can be innovated and implemented for the network. GANA DEs are meant to drive control-loops within Network Elements/Functions (NEs or NFs) of the 5G network infrastructure and/or drive control-loops at the higher level of abstraction for self-management functionality that is positioned within the outer Management and Control realm of a 5G Network Infrastructure - within a platform called the GANA Knowledge Plane (KP) Platform that uses complex AI algorithms to dynamically and adaptively (re)-configure the network and services using management and control systems such as OSS/BSS, SDN Controllers, Orchestrators, MANO stacks, etc. DE algorithms are not subject to standardization as they provide for the space for innovation and DE and Algorithm supplier differentiations. Examples of Autonomic Functions (i.e. GANA DEs) are: *QoS-management-DE*, *Security-management-DE*, *Mobility-management-DE*, *Fault-management-DE*, *Resilience & Survivability-DE*, *Service & Application management-DE*, *Forwarding-management-DE*, *Routing-management-DE*, *Monitoring-management-DE*, *Generalized Control Plane management-DE*.

The Framework presented in the present document prescribes how to utilize IPv6 Capabilities and emerging IPv6 Extensions in implementing GANA DEs powered Autonomic/Autonomous IPv6 based E2E 5G Network. Innovators obtain guidance on the types of GANA DEs that should be designed to auto-configure and dynamically (autonomically/adaptively) orchestrate and (re)-configure various Managed Entities (MEs), including IPv6 Protocols as MEs of the 5G Network, as driven by Service or Slice provisioning, or adaptively to meet certain objectives. DEs also provide the means to intelligently adapt the network to various kinds of detected and predicted situations and challenges the autonomic 5G network may experience during its operation.

Introduction

Artificial Intelligence Models (AI Models) are enablers for advanced intelligence in the management and control operations now strongly required for the evolving and future networks such as 5G Networks. AI algorithms bring benefits to diverse aspects in development and deployment of AI exhibiting systems such as Autonomic (Closed-Loop) and Cognitive 5G networks and their associated Autonomic Management and Control systems. European Telecommunications Standards Institute (ETSI) Technical Committee (TC) INT/AFI Working Group (WG) has recently published the de-facto standard on the Generic Autonomic Networking Architecture (GANA) Reference Model - An Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services in which AI plays a role in autonomic management and control of networks and services [i.2]. ETSI TS 103 195-2 [i.2] defines an Intelligent Management and Control Functional Block called GANA Knowledge Plane (KP) that is an integral part of Management and Control Systems for the network. GANA KP Platform host complex AI powered network analytics functions that are performed by interworking modules for autonomic (closed-loop) decision-making and execution called GANA Decision-making-Elements (DEs).

The KP DEs run as software in the Knowledge Plane (KP) Platform and drive **self-* operations such as self-adaptation, self-optimization, self-monitoring, self-protection and self-defense** objectives for the network and services by programmatically (re)-configuring Managed Entities (MEs) in the network infrastructure through various means possible. The means to program MEs include NorthBound Interfaces available at the Operations Support Systems (OSS), Service Orchestrator, Domain Orchestrator, Software Defined Networking (SDN) controller, Element Management System/Network Management System (EMS/NMS), Network Functions Virtualisation (NFV) Orchestrator, etc. KP DEs are powered by Artificial Intelligence (AI) algorithms such as Machine Learning (ML), Deep Learning (DL), computational intelligence, etc., such that they execute as AI models or components that embed AI Models [i.2], [i.3], [i.7], [i.6] and [i.11].

ETSI TC INT/ AFI WG has established that E2E Autonomic (Closed-Loop) Service and Security Assurance should be achievable through the Federation of GANA Knowledge Planes (KPs) Platforms that implement components for Autonomic Management and Control (AMC) intelligence for specific network segments and domains. The ETSI GANA Framework enables to define and standardize such a framework. Autonomics by the GANA Knowledge Plane (KP) for a particular network segment/domain is complemented by lower level autonomics introduced in Network Elements/Functions (NEs/NFs) of the particular network segment under the responsibility of the KP, such that the KP policy-controls the lower level autonomics introduced in NEs/NFs. The E2E federation of KPs for the various network segments/domains and their policy-controlling of lower levels autonomics in the NEs/NFs of their respective network segments enable to achieve the complementary multi-layer autonomics. The complementary multi-layer autonomics and the federations of KP Platforms should realize (achieve) Holistic Multi-Domain State Correlation and resources programming by the GANA KPs for the network segments/domains such as the Access, X-Haul (Fronthaul, Midhaul and Backhaul), and Core Networks, etc. While such an E2E Federation of KP Platforms for multiple network segments (as domains) has to be primarily considered within a single network operator administrative domain, the E2E Federation of KPs may be extended to even span multiple network operators' or enterprises' network administrative domains.

ETSI TC INT/AFI WG Specifications such as ETSI TR 103 404 [i.5], ETSI TR 103 495 [i.13], ETSI TR 103 473 [i.4], and ETSI TR 103 747 [i.63] provide the answer to the question of how to implement GANA-defined autonomic manager components (called autonomic functions, i.e. GANA DEs) that implement control-loops in physical Network Elements/Functions (NEs/NFs) and in Virtualised Network Functions (VNFs). This includes answers to how to complement the NE/NF Level autonomic manager components with autonomic manager components defined to operate in the realm outside of NEs/NFs (the realm of management and control systems for particular network architectures), i.e. in the realm called the GANA Knowledge Plane (KP).

ETSI TC INT/AFI WG is also running a Proof-Of-Concept (PoC) Program on **5G Network Slices Creation, Autonomic & Cognitive Management & End-to-End (E2E) Orchestration; with Closed-Loop (Autonomic) Service Assurance of 5G Slices**, as described in clause 10 of the present document.

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1 Scope

The present document is a Framework (Guide) to Implementing Autonomic/Autonomous IPv6 based 5G Networks, by leveraging the ETSI GANA Multi-Layer AI / Multi-Layer Autonomic Management and Control Model and IPv6 Capabilities & Extensions that enable to Build Autonomic Networks. The Framework prescribes how to introduce software components called Autonomic Functions (ETSI GANA Decision-making-Elements (DEs)), e.g. Autonomic-QoS-Management-DE, Autonomic-Security-Management-DE, etc. in the 5G Architecture and its associated Management and Control Architecture. The DEs and their associated Algorithms (including analytics, optimization and AI algorithms) are meant to drive control-loops within Network Functions of the 5G network infrastructure and/or drive control-loops at the higher level of abstraction for self-management functionality that is positioned within the outer Management and Control realm of a 5G Network Infrastructure - within a platform called the GANA Knowledge Plane (KP) Platform. The Framework also serves to:

- prescribe how to leverage certain IPv6 Capabilities in enabling Autonomic Functions (called Decision-making-Elements (DEs) in the present document) of the Autonomic 5G network to auto-discover each other, auto-discover various context information, monitoring data, and to exchange DE-to-DE control messages among each other for their collaborative operations in the Self-Driving/Self-Management Operations of the 5G network(s);
- provide Guidance to Innovators of DEs and their associated Autonomics Algorithms, on the types of GANA DEs that should be designed to auto-configure and dynamically (autonomically) orchestrate and (re)-configure various IPv6 Protocols of the 5G Network as driven by Service or Slice provisioning, or adaptively to meet certain objectives.

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 may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.

- [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".
- [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".
- [i.3] [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".
- [i.4] [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".

- [i.5] 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.6] [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".
- [i.7] [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".
- [i.8] 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.9] ETSI TS 128 533 (V15.0.0): "5G; Management and orchestration; Architecture framework (3GPP TS 28.533 version 15.0.0 Release 15)".
- [i.10] NGMN Alliance: ["5G End-to-End Architecture Framework v3.0.8"](#).
- [i.11] [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)".
- [i.12] 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.13] 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.14] Ranganai Chaparadza, Michal Wodczak, Tayeb Ben Meriem, Paolo De Lutiis, Nikolay Tcholtchev, Laurent Ciavaglia: "Standardization of resilience & survivability, and autonomic fault-management, in evolving and future networks: An ongoing initiative recently launched in ETSI", In proceedings of 2013 9th International Conference on the Design of Reliable Communication Networks (DRCN 2013), ISBN 9781479900497, 4-7 March 2013, Budapest, Hungary.
- [i.15] [IETF RFC 9386](#): "IPv6 Deployment Status".
- [i.16] Reliance Jio: ["IPv6-only adoption challenges and standardization requirements"](#), 2020.
- [i.17] T-Mobile US: "Going IPv6-only", 2018.
- [i.18] Carl A. Sunshine: "Source Routing In Computer Networks", ACM SIGCOMM Computer Communication Review Volume 7, Issue 1, January 1977, pp. 29–33.
- [i.19] IETF RFC 8754: "IPv6 Segment Routing Header (SRH)", March 2020.
- [i.20] IETF RFC 8986: "Segment Routing over IPv6 (SRv6) Network Programming", February 2021.
- [i.21] ETSI GR IPE 001 (V1.1.1) (2021-08): "IPv6 Enhanced Innovation (IPE); Gap Analysis".
- [i.22] ETSI TS 123 501 (V16.6.0) (2020-10): "5G; System architecture for the 5G System (5GS) (3GPP TS 23.501 version 16.6.0 Release 16)".
- [i.23] IETF RFC 5120: "M-ISIS: Multi Topology (MT) Routing in Intermediate System to Intermediate Systems (IS-ISs)", February 2008.
- [i.24] IETF RFC 4915: "Multi-Topology (MT) Routing in OSPF", June 2007.
- [i.25] IETF draft-ietf-teas-ietf-network-slices: "A Framework for IETF Network Slices", January 2023 (work in progress).

- [i.26] IETF RFC 9350: "IGP Flexible Algorithm", February 2023.
- [i.27] IETF RFC 9256: "Segment Routing Policy Architecture", July 2022.
- [i.28] IETF RFC 5440: "Path Computation Element (PCE) Communication Protocol (PCEP)", March 2009.
- [i.29] ETSI White Paper No. 16: "GANA - Generic Autonomic Networking Architecture".
- [i.30] IETF RFC 9313: "Pros and Cons of IPv6 Transition Technologies for IPv4-as-a-Service (IPv4aaS)", October 2022.
- [i.31] IETF RFC 6146: "Stateful NAT64: Network Address and Protocol Translation from IPv6 Clients to IPv4 Servers", April 2011.
- [i.32] IETF RFC 6147: "DNS64: DNS Extensions for Network Address Translation from IPv6 Clients to IPv4 Servers", April 2011.
- [i.33] IETF RFC 6877: "464XLAT: Combination of Stateful and Stateless Translation", April 2013.
- [i.34] IETF RFC 6333: "Dual-Stack Lite Broadband Deployments Following IPv4 Exhaustion", August 2011.
- [i.35] ETSI TS 103 878: "Core Network and Interoperability Testing (INT); Network Interoperability Test Description for IPv6-only services over 5G".
- [i.36] ETSI GR IP6 010: "IPv6-based SDN and NFV; Deployment of IPv6-based SDN and NFV".
- [i.37] IETF RFC 9341: "Alternate-Marking Method", December 2022.
- [i.38] IETF RFC 9342: "Clustered Alternate-Marking Method", December 2022.
- [i.39] IETF RFC 6241: "Network Configuration Protocol (NETCONF)", June 2011.
- [i.40] IETF RFC 7752: "North-Bound Distribution of Link-State and Traffic Engineering (TE) Information Using BGP", March 2016.
- [i.41] IETF RFC 8571: "IGP Traffic Engineering Performance Metric Extensions", March 2019.
- [i.42] IETF draft-ietf-idr-segment-routing-te-policy: "Advertising Segment Routing Policies in BGP", July 2022 (work in progress).
- [i.43] R. Chaparadza, S. Papavassiliou, S. Soulhi and J. Ding: "The Self-Managing Future Internet powered by the current IPv6 and extensions to IPv6 towards "IPv6++" — A viable roadmap Scenario for the Internet Evolution Path", 2010 IEEE™ Globecom Workshops, 2010, pp. 551-556, doi: 10.1109/GLOCOMW.2010.5700381.
- [i.44] Chaparadza, R., Petre, R., Prakash, A., Németh, F., Kukliński, S., Starschenko, A. (2011): "[IPv6 and Extended IPv6 \(IPv6++\) Features That Enable Autonomic Network Setup and Operation](#)", In: Szabó, R., Zhu, H., Imre, S., Chaparadza, R. (eds) Access Networks. AccessNets 2010. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 63. Springer, Berlin, Heidelberg.
- [i.45] A. Starschenko, N. Tcholtchev, A. Prakash, I. Schieferdecker and R. Chaparadza: "Auto-configuration of OSPFv3 routing in fixed IPv6 networks", 2015 7th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), 2015, pp. 196-205, doi: 10.1109/ICUMT.2015.7382427.
- [i.46] Ranganai Chaparadza, Tayeb Ben Meriem, Benoit Radier, Szymon Szott, Michal Wódczak, Arun Prakash, Jianguo Ding, Said Soulhi, Andrej Mihailovic: "Implementation Guide for the ETSI AFI GANA model: A Standardized Reference Model for Autonomic Networking, Cognitive Networking and Self-Management", 2013 IEEE™ Globecom Workshops (GC Wkshps), 2013, pp. 935-940, doi: 10.1109/GLOCOMW.2013.6825110.

- [i.47] N. Tcholtchev, A. Prakash, I. Schieferdecker, R. Chaparadza and R. Petre: "Auto-Collaboration for optimal network resource utilization in fixed IPv6 networks", 2012 IEEE™ Globecom Workshops, 2012, pp. 807-812, doi: 10.1109/GLOCOMW.2012.6477679.
- [i.48] Kaldanis, V., Benko, P., Asztalos, D., Simon, C., Chaparadza, R., Katsaros, G. (2011): "[Methodology towards Integrating Scenarios and Testbeds for Demonstrating Autonomic/Self-managing Networks and Behaviors Required in Future Networks](#)", In: Szabó, R., Zhu, H., Imre, S., Chaparadza, R. (eds) Access Networks. AccessNets 2010. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 63. Springer, Berlin, Heidelberg.
- [i.49] Prakash, A., Starschenko, A., Chaparadza, R. (2011): "[Auto-discovery and Auto-configuration of Routers in an Autonomic Network](#)", In: Szabó, R., Zhu, H., Imre, S., Chaparadza, R. (eds) Access Networks. AccessNets 2010. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 63. Springer, Berlin, Heidelberg.
- [i.50] Rétvári, G., Németh, F., Chaparadza, R., Szabó, R. (2009): "[OSPF for Implementing Self-adaptive Routing in Autonomic Networks: A Case Study](#)", In: Strassner, J.C., Ghamri-Doudane, Y.M. (eds) Modelling Autonomic Communications Environments. MACE 2009. Lecture Notes in Computer Science, vol. 5844. Springer, Berlin, Heidelberg.
- [i.51] Zafeiropoulos, A., Liakopoulos, A., Davy, A., Chaparadza, R. (2010): "[Monitoring within an Autonomic Network: A GANA Based Network Monitoring Framework](#)", In: Dan, A., Gittler, F., Toumani, F. (eds) Service-Oriented Computing. ICSOC/ServiceWave 2009 Workshops. ServiceWave ICSOC 2009 2009. Lecture Notes in Computer Science, vol. 6275. Springer, Berlin, Heidelberg.
- [i.52] Szymon Szott, Janusz Gozdecki, Katarzyna Kosek-Szott, Krzysztof Loziak, Marek Natkaniec, Michal Wagrowski, Ranganai Chaparadza: "[Enabling autonomicity in wireless mesh networks with the ETSI AFI GANA reference model](#)", International Journal of Network Management, First published: 01 August 2017.
- [i.53] "Evolution of the current IPv6 towards IPv6++ (IPv6 with Autonomic Flavours", In: International Engineering Consortium (IEC) Annual Review of Communications, vol. 60 (December 2008).
- [i.54] Georgios Aristomenopoulos, Timotheos Kastrinogiannis, Zhaojun Li & Symeon Papavassiliou: "[An Autonomic QoS-centric Architecture for Integrated Heterogeneous Wireless Networks](#)", Mobile Netw Appl 16, 490–504 (2011).
- [i.55] G. Aristomenopoulos, T. Kastrinogiannis, Z. Li, M. Wilson, M. González Juan, A. Lozano-López Jose, Y. Li, V. Kaldanis, S. Papavassiliou: "Autonomic mobility and resource management over an integrated wireless environment — A GANA oriented architecture", 2010 IEEE™ Globecom Workshops, Miami, FL, USA, 2010, pp. 545-550, doi: 10.1109/GLOCOMW.2010.5700379.
- [i.56] Z. Li: "An autonomic hierarchical mobility management framework for 3GPP heterogeneous networks", 2010 Future Network & Mobile Summit, Florence, Italy, 2010, pp. 1-8.
- [i.57] A. Jaron, P. Pangalos, A. Mihailovic, A.H. Aghvami: "Proactive autonomic load uniformisation with mobility management for wireless Internet Protocol (IP) access networks", Source: Volume 1, Issue 4, December 2012, p. 229 - 238: doi: 10.1049/iet-net.2011.0009, Print ISSN 2047-4954, Online ISSN 2047-4962.
- [i.58] A. Liakopoulos, A. Zafeiropoulos, C. Marinos, M. Grammatikou, N. Tcholtchev and P. Gouvas: "Applying distributed monitoring techniques in autonomic networks", 2010 IEEE™ Globecom Workshops, Miami, FL, USA, 2010, pp. 498-502, doi: 10.1109/GLOCOMW.2010.5700369.
- [i.59] [European Commission \(EC\) funded FP7](#): "Exposing the Features in IP version Six protocols that can be exploited/extended for the purposes of designing/building Autonomic Networks and Services".
- [i.60] [IETF draft-chaparadza-6man-igcp-00](#): "IETF Autonomic Networking Integrated Model and Approach (anima)".
- [i.61] [IETF draft-chaparadza-6man-igcp-00.txt](#): "ICMPv6 based Generic Control Protocol (IGCP)".

- [i.62] European Commission funded -EFIPSANS-FP7-IP Project: Deliverable-D3.2: "[Advanced Network Services in Autonomic IPv6 Networking: Performance Analysis and Evaluation](#)", issued on 31.12.2009 (accessed November 2023).
- [i.63] ETSI TR 103 747 (V1.1.1): "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".
- [i.64] EANTC: "[MPLS SDN Interoperability Test 2023](#)", SRv6 test.
- [i.65] ETSI GR IPE 005 (V1.1.1): "IPv6 Enhanced Innovation (IPE); 5G Transport over IPv6 and SRv6".
- [i.66] ETSI TR 103 626: "Autonomic network engineering for the self-managing Future Internet (AFI); An Instantiation and Implementation of the Generic Autonomic Network Architecture (GANA) Model onto Heterogeneous Wireless Access Technologies using Cognitive Algorithms".
- [i.67] ETSI White Paper No. 35: "IPv6 Best Practices, Benefits, Transition Challenges and the Way Forward", First edition, August 2020.
- [i.68] oneM2M TR-436: "Access & Home Network OAM Automation/Intelligence", Issue: 1 Issue Date: February 2021.
- [i.69] IETF RFC 8992 (2021): "Autonomic IPv6 Edge Prefix Management in Large-Scale Networks".
- [i.70] IETF RFC 8990: "GeneRic Autonomic Signalling Protocol (GRASP)".
- [i.71] Recommendation ITU-T Y.3324: "Requirements and architectural framework for autonomic management and control of IMT-2020 networks".
- [i.72] IETF RFC 7596: "Lightweight 4over6: An Extension to the Dual-Stack Lite Architecture".
- [i.73] IETF RFC 7599: "Mapping of Address and Port using Translation (MAP-T)".
- [i.74] IETF RFC 7597: "Mapping of Address and Port with Encapsulation (MAP-E)".

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	3 rd Generation Partnership Project
5G SA	5G StandAlone
AcN	Autonomic Network
AFI	Autonomic Future Internet
AFTR	Address Family Transition Router
AGG	AGgregation Gateway
AI	Artificial Intelligence
AMC	Autonomic Management & Control
AMF	Access and Mobility Management Function
AN	Autonomous Network

ANIMA	Autonomic Networking Integrated Model and Approach
API	Application Programming Interfaces
APN	Application - aware Networking
APN6	Application - aware IPv6 Networking
AS	Autonomous System
ASN	Autonomous System Number
ATS	Abstract Test Suite
BBF	BroadBand Forum
BFD	Bidirectional Forwarding Detection
BGP	Border Gateway Protocol
BGP-LS	Border Gateway Protocol Link-State
CAPEX	CAPital EXpenditure
CLAT	Client-side NAT
CLI	Command Line Interface
CPE	Customer Premises Equipment
CSG1	Communication Systems Group
C-SON	Centralized Self Organizing Network
DC	Data Centre
DE	Decision making Element
DL	DownLink
DNS	Domain Name System
DS-lite	Dual Stack lite
D-SON	Distributed - Self Organizing Network
E2E	End-to-End
EC	European Community
ECMP	Equal-Cost Multi-Path
EMS	Element Management System
EPC	Evolved Packet Core
FBB	Fixed BroaBand
FlexE	Flexible Ethernet
FP7	Seventh Framework Programme
FW	FireWall
GAN	Generic Autonomic Network Architecture
GRASP	GeneRic Autonomic Signalling Protocol
IANA	Internet Assigned Numbers Authority
ICMP	Internet Control Message Protocol
ICT	Information and Communications Technology
IFIT	In-situ Flow Information Telemetry
IGCP	ICMPv6 based Generic Control Protocol
IGP	Interior Gateway Protocol
IKE	Internet Key Exchange
IMS	IP Multimedia Subsystem
IoT	Internet of Thing
IP	Internet Protocol
IPE	IPv6 Enhanced innovation
IS-IS	Intermediate System-to-Intermediate System
ISP	Internet Service Provider
KP	Knowledge Plane
KP DE	Knowledge Plane Decision-making Element
KPI	Key Performance Indicator
MANO	Management and Orchestration
MAP-E	Mapping of Address and Port with Encapsulation
MAPE-K	Monitor-Analyse-Plan-Execute over a shared Knowledge
MAP-T	Mapping of Address and Port using Translation
MBB	Mobile BoradBand
MBTS	Model-Based Translation Service
MDAS	Management Data Analytics Service
ME	Managed Entity
MEC	Mobile Edge Computing
ML	Machine Learning
mMTC	massive Machine Type Communications
MPLS	MultiProtocol Label Switching

NAT	Network Address Translation
NB	NorthBound
NE	Network Element
NF	Network Function
NFV	Network Function Virtualisation
NGMN	Next Generation Mobile Networks
NSSF	Network Slice Selection Function
NWDAF	NetWork Data Analytics Function
NWDAS	NetWork Data Analytic Service
OAM	Operations Administration and Maintenance
ODA	Open Digital Architecture
ONIX	Overlay Network for Information eXchange
OPEX	OPerating EXpenses
O-RAN	Open RAN
OSe	Operating System embedded
OSPF	Open Shortest Path First
OSS	Operations Support Systems
PE	Provider Edge
PLAT	Provider-side NAT
PoC	Proof of Concept
Pre-AGG	Pre-Aggregation Gateway
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAN	Radio Access Network
RIC	RAN Intelligent Controllers
RR	Route Reflectors
SBA	Service Based Architecture
SDN	Software Defined Networks
SDO	Standards Development Organizations
SDWAN	Software-Defined Wide Area Network
SEG	Secure Gateway
SID	Segment Identifier
SLA	Service Level Agreement
SMF	Session Management Function
SNMP	Simple Network Management Protocol
SON	Self Organizing Networks
SPAN	Switched Port Analyser
SPF	Shortest Path First
SR-BE	Segment Routing Best Effort
SRH	Segment Routing Header
SR-PCE	Segment Routing - Path Computation Engine
SR-TE	Segment Routing - Traffic Engineering
TAP	Test Access Points
TE	Traffic Engineering
TLV	Type-Length-Value
TWAMP	Two-Way Active Measurement Protocol
UE	User Equipment
UPF	User Plane Function
URLLC	Ultra Reliable and Low Latency Communications
VNF	Virtual Network Function
VRF	Virtual Routing and Forwarding
WAN	Wide Area Network
WG	Working Group
YANG	Yet Another Next Generation

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

This clause refers to clause 4 of ETSI TR 103 747 [i.63].

The Generic Autonomic Networking Architecture (GANA) Reference Model serves as a standardized architectural framework for autonomic networking, cognitive networking, and self-management of networks and services. It defines a hierarchy of Functional Blocks (FBs) that implements a control-loop as the core driver of the self-management, their reference points, and messaging protocols, supporting both micro-level (within network elements) and macro-level (network-wide) autonomic control loops.

Central to GANA is the Knowledge Plane (KP), which orchestrates intelligent management and control through key components such as network-level Decision-making Elements (DEs), the ONIX overlay for distributed information exchange, and the Model-Based Translation Service (MBTS) for protocol-agnostic communication between DEs and network elements. GANA's hybrid approach allows implementers flexibility in deploying autonomic logic either centrally (macro-autonomics) or in a distributed manner (micro-autonomics), and is compatible with hybrid Self-Organizing Networks (SON) models.

GANA DEs are organized hierarchically to enable scalable and coordinated autonomic management. Higher-level DEs, often situated within the Knowledge Plane (KP), exercise supervisory control over lower-level DEs and Managed Entities (MEs) by implementing intent-driven, closed control loops.

Specifically, a higher-level DE analyses aggregated network-wide data and determines the appropriate intent or configurations. It then communicates directives, intent/policies, or configuration parameters to subordinate DEs, which are instantiated within specific network elements or functions. These lower-level DEs, in turn, execute fast, localized control loops—directly managing the behavior and state of their respective MEs based on the guidance received from the higher-level DE.

This hierarchical control structure ensures that overarching network objectives are maintained, while allowing for rapid, context-aware adjustments at the local level. The approach enables seamless coordination between macro-level (network-wide) and micro-level (element-specific) autonomics, promoting both global optimization and local agility in network management.

GANA facilitates integration with diverse management and control systems as depicted in Figure 1 with NorthBound (NB) Application Programming Interfaces (API) (e.g. SDN controllers, OSS/BSS, NFV MANO), leveraging standardized APIs to enable end-to-end orchestration and analytics. GANA also addresses the coordination and collaboration among autonomic functions, the handling of intent-based networking, and the design principles necessary for the stability and synchronization of control loops, positioning itself as a holistic and unifying framework for autonomic management and control.