The Era of Knowledge Plane (KP) Platforms Driven Networking—Anchor for Federation of Autonomic/Autonomous Networks (ANs) Across Industry Sectors

Ranganai Chaparadza[1], Muslim Elkotob[2], Benoit Radier [3], Tayeb Ben Meriem[4], Taesang Choi[5], Robert B. Bohn[6], Abdella Battou[7], Tao Zhang[8]

Abstract — Future Networks, Beyond 5G and 6G, will continue to expand in scale, complexity and interconnectivity, and will be highly shaped by distributed systems that serve various use cases that go beyond current Use Cases like mMTC (massive Machine Type Communications) and URLLC (Ultra Reliable Low Latency Communications). This will be coupled with an increasing demand for autonomy in self-organization and self-management, automation and interoperability on a very dynamic flexible basis. Systems-of-systems architectures will become more relevant as multiple autonomous/semi-autonomous systems adaptively seek to operate and interact with their peers (including the advent of so-called "symbiotic autonomous systems"). Research on autonomous systems and autonomic networks recognizes the benefits to interacting with other systems when needed and should explore frameworks that will enable this dynamic interactivity under the emerging concept of Federation of Autonomic/Autonomous networks (ANs). Autonomy and Degree of Autonomy in ANs should be subjected to "governance by humans" through ANs exposure of Governance Interfaces to make sure ANs solely serve purposes that humans expect of them and not negatively impact environment and society. The use of Federation and in some cases Governance interfaces and mechanisms is a promising technology for interconnecting systems, innovation and service delivery by the federating AN systems; and allowing asset sharing and extending traditional eco-systems and value-chains with further resources and stakeholders (including new ones that were never involved in the traditional ICT ecosystems but should now be involved in 5G and 6G ecosystems). ETSI has standardized the concept of so-called GANA (Generic Autonomic Network Architecture) Knowledge Plane (KP) Platform that drives closed-control-loops for Autonomic Management and Control (AMC) operations for a specific ICT network segment(s)—making the network management and operation of the network segment autonomous to some degree (as an AN). The paper provides an analysis of the aspects of relevance to the broader picture of ANs in standardization efforts, multi-layer autonomic systems design and operational principles, federation and governance of ANs, progress in standards, so as to provide contributions on what needs to be complemented to ongoing efforts in standardization groups. But the major contribution of this paper is on the aspect of *Requirements for Knowledge Plane (KP) Platforms Driven Networking, by which KP Platforms play the role of anchors for Federation of Autonomic/Autonomous Networks (ANs) Across Industry Sectors*. Whereby we consider that KP Platforms should be the anchor Functional Entities through which Federation and Governance of ANs should be achieved such that the federated ANs deliver end-to-end services in an *agile and on-demand manor* in fulfilling various dynamic communication services needs required for consumption by humans and by machines, and through which resilience and survivability of ICT network infrastructures and services should be achieved through collaborative actions and intelligence of the GANA KP Platforms. Requirements we study include the role of KPs in *Composable Networks*, *Composable Services*, *Enablers such as Cloud Federations APIs*, *Autonomic Network Formations*, *How KPs build Knowledge and can exchange Knowledge and negotiated operations/actions* for *Self-* AMC intelligence* within and across federated ANs, e.g., *Self-Optimizations, Self-Protection, Self-Diagnosis and Self-Healing, etc*.

Index Terms—Autonomic/Autonomous Networking (AN); Federations & Governance of ANs; Multi-Layer Autonomics and AI/ML Frameworks; Autonomic Management & Control (AMC); Autonomics Levels; Degrees of Autonomy in ANs

I. Autonomic/Autonomous Networks (ANs) in B5G/6G and Degrees of Autonomy in the Evolution of ANs

The quest for smart and intelligent cognitive systems that are powered by control-loops for the Autonomics paradigm, Cognition (learning and reasoning) enablers, Artificial Intelligence (AI) Models/Algorithms and Computational Intelligence, is increasingly on the sharp rise in various industry sectors, such as traditional ICT networks (e.g., Access Networks, Transport and Core Networks, Data Center Networks, IT enterprise networks and environments) that facilitate human service consumption (e.g. voice, video and data call services); Manufacturing; Automotive; Aerospace; Healthcare; Mining; and many other industry sectors. In ICT networks (public and enterprise private networks), the need for

[1]Ranganai Chaparadza: ETSI AFI & IPv6Forum: ran4chap@yahoo.com
[2]Muslim Elkotob Vodafone, ETSI AFI: muslim.elkotob@vodafone.com
[3] Benoit Radier: Orange, ETSI AFI: benoit.radier@orange.com
[4]Tayeb Ben Meriem: IPv6 Forum: tay.b52@yahoo.com
[5]Taesang Choi: ETRI: choits@etri.re.kr
[6]Robert B. Bohn: NIST: robert.bohn@nist.gov
[7]Abdella Battou: NIST: abdella.battou@nist.gov
[8]Tao Zhang: NIST: tao.zhang@nist.gov

network automation and related standards has continued to grow, mainly because it is becoming increasingly very difficult to manage the increasingly complex networks and technologies using traditional manual management of networks. For ICT Network Operators (Communications Service Providers (CSPs)) who operate the evolving and future networks such as 4G, 5G and Beyond networks, there is need for a shift to the way ICT networks are designed and operated. A shift to a new way that brings about OPEX sustainability in operating networks and services and enables operators and enterprises to innovate and deliver services to consumers in a richly agile manner—thanks to self-managed (intelligent) networks. Hence, there has been huge efforts recently launched in various SDOs/Fora in producing Standards for Cognitive/Autonomic Management and Control (AMC) of ICT Networks and Services—powered by Control-Loops for Autonomics, Artificial Intelligence (AI) Models/Algorithms and Computational Intelligence. Systems at various levels of abstractions within the various industry sectors, ranging from Network Elements/Functions of ICT infrastructures and associated Management and Control Systems/Platforms of the ICT infrastructures that serve consumer devices and services delivered for human consumptions (e.g., voice, video and data communication services); Industrial Robots in the Manufacturing sector; Service Robots; Robots or ICT systems used in healthcare and other sectors; elements or systems in the scope of Internet of Things (IoT), and in other scopes; should be designed to incorporate Control-Loops for Autonomics, Cognition, Artificial Intelligence (AI) Models/Algorithms and Computational Intelligence at varying degrees of complexity. Such design principles for the various systems shall enable the systems (individually and collaboratively within certain scopes/boundaries) to be smart and intelligent (cognitive, with learning and reasoning capabilities) and exhibit the so-called Self-* behavioral attributes/features such as *Auto-Discovery of Resources, Information, Context-changes or environments*; *Self-Configuration; Self-Diagnosis; Self-Repair; Self-Optimization; Self-Protection; Self-Defense; Self-Healing; Self-Awareness, Self-Organizing; Self-Adapting attributes; etc.* The characterization of such systems is often described as Self-Managing Systems (includes Self-Organizing Systems). [4][5] present and discuss the taxonomical relationships between an "***Autonomic Network (AN)***" and an "***Autonomous Network (AN)***", and how the concept of *autonomicity (autonomics)* is an enabler for achieving autonomous network property and behaviour. The industry has classified the various systems and related initiatives in Standardization under the general umbrella of the so-called Autonomic/Autonomous Networks (ANs). Under the umbrella of ANs we find smart/intelligent (cognitive) systems in the scope of traditional ICT networks; as well as smart/intelligent (cognitive) systems in the scope of Machine-to-Machine or IoT Systems; smart/intelligent (cognitive) systems in the scope Industrial Robots or Service Robots; smart/intelligent (cognitive) systems in the scope Autonomous/Self-Driving Vehicles; smart/intelligent (cognitive) systems in the scope of Drones; smart/intelligent (cognitive) systems in the scope of other sectors. In some SDOs/Fora, there are other classifications such as Robotics and Autonomous Systems (RAS) classifications in

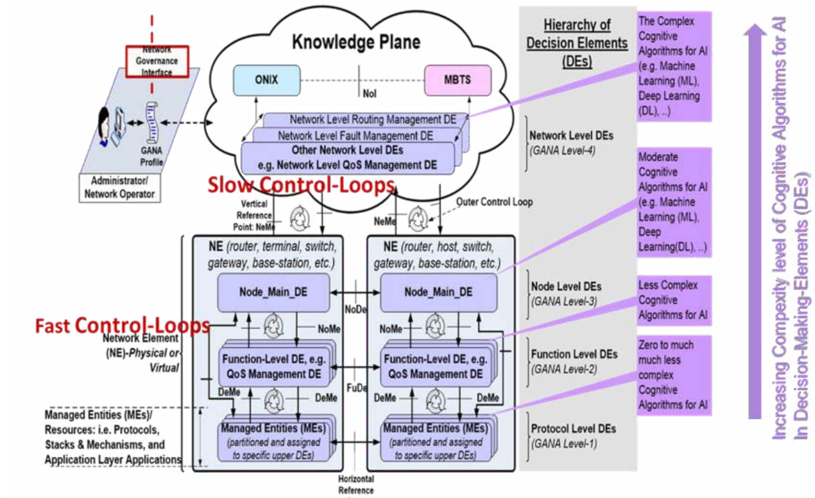

Figure 1: ETSI GANA Reference Model, Decision Elements (DEs) at GANA Abstraction-Levels for Autonomics, Modularization of logically centralized AMC Software (GANA Knowledge Plane)

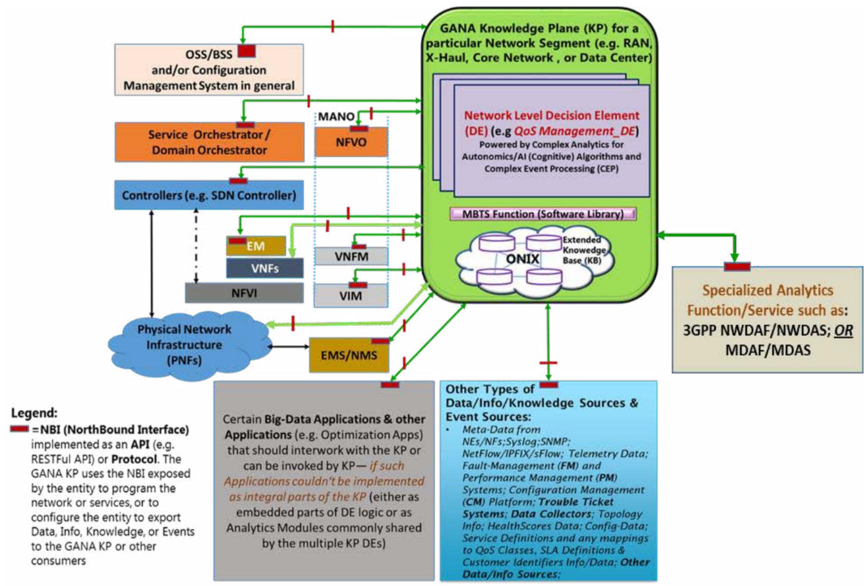

Figure 2: Integration of the GANA KP Platform with various management and control systems through which the KP can selectively program the network; KP integration with Event Sources, Data Sources and Info/Knowledge Sources

ETSI White Paper No. 45. Some initiatives keep the classification of Autonomous Networks to ICT networks only. While other related work in other various SDOs/Fora has focused on Autonomic Networks (and interchangeably called Autonomous Networks too) as a classification, but mostly in the scope of traditional ICT networks. There is a lot of AN related work in ETSI, IEEE, ITU-T, BBF, TM Forum, 3GPP, and in other SDOs/Fora. ETSI has recently published the Generic Autonomic Networking Architecture (GANA) Standard (ETSI TS 103 195-2), an Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services in which Control-Loops, Cognition, Artificial Intelligence (AI) and Computational Intelligence play a role in Autonomic Management and Control (AMC) of ICT networks and services [1]. Figure 1 is a snapshot of the ETSI GANA Model, which is fully described in ETSI TS 103 195-2 [1], including the concept of Autonomic Functions called Decision-making-Elements (DEs). The GANA Model is being instantiated over various network architectures and their associated management and control architectures and has been adopted by many SDOs/Fora in embedding autonomics in their architectures as illustrated in [2]. As described in [1] [3] [4] [5] the ETSI GANA ushers in the era of the so-called *GANA Knowledge Planes (KPs) Driven Networking* now and into the future. Figure 2 presents the concept of a GANA Knowledge Plane (KP), which is described in more detail in ETSI TR 103 747 and in ETSI TS 103 195-2. A GANA KP Platform shall drive *self-* operations for AMC such as self-adaptation, self-optimization, self-monitoring, self-protection and self-defense, and other self-** objectives for the network and services within a certain scope and shall federate with other GANA KPs responsible for other network scopes and domains so that the federated GANA KPs drive collaborative AMC operations across domains. Recently a so-called Multi-SDO Initiative was created in 2021 on Autonomous Networks (ANs) that covers the general broad umbrella of Autonomic/Autonomous Networks (ANs), and the Multi-SDO initiative on ANs (dubbed "*Multi SDO Autonomous Network coordination"*) is hosted by TM Forum [10].

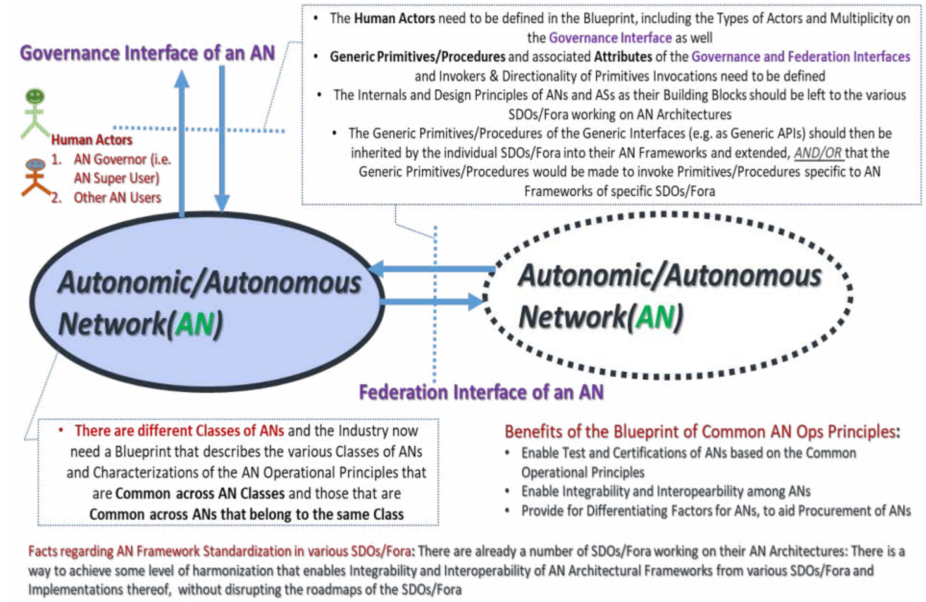

Figure 3: Conceptual Model of an AN's Key Operations-related Peripheral Interfaces for consideration, namely the "Governance Interface" and "Federation Interface" (courtesy of IEEE [3])

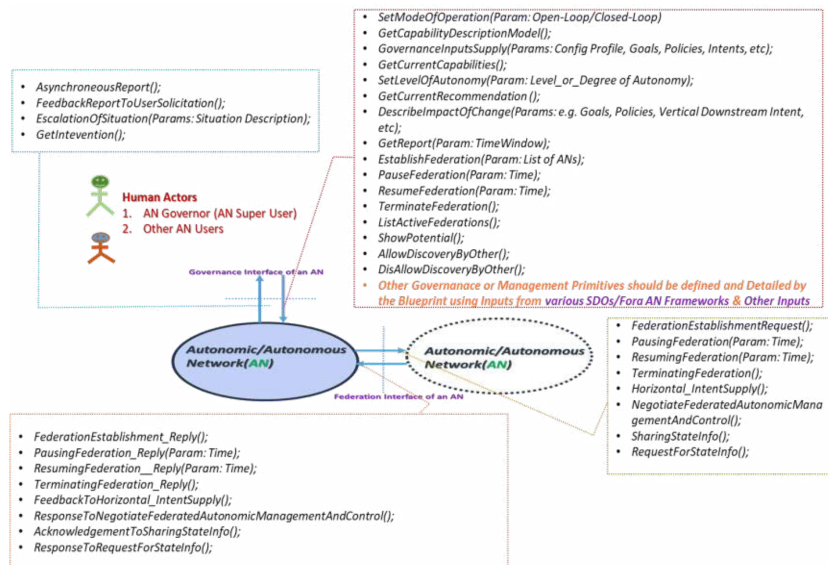

Figure 4: Examples of Primitives of the Conceptual Model that would need to be specified and detailed in the COPAAN Blueprint (courtesy of IEEE [3])

The implementation of ANs is associated with *levels of autonomy* or *degree of autonomy* as discussed in ETSI TR 103 747 and in a recently published TM Forum white paper that defines six levels of autonomy in [7]. ETSI TR 103 747 establishes and discusses the relationship between autonomics (autonomicity) and the network behavioral property of being "autonomous". The ITU-T Focus Group on Autonomous Networks (ITU-T FG-AN) includes some deliverables that discuss the subject of levels of autonomy in ANs [7]. [6][8] provide good survey on AN-related standardizations.

II. Governance and Federation Interfaces and Associated APIs for Autonomic/Autonomous Networks (ANs) in 5G and Beyond

In this section we analyze efforts emerging from the Multi-SDO community as described in the IEEE NGR (International Network Generations Roadmap) 2022 EDITION—IEEE INGR (International Network Generations Roadmap)/Future Networks, Systems Optimization Roadmap Chapter, regarding the need for the industry to develop a standardized Blueprint of Common Operational Principles for Autonomic/Autonomous Networks (COPAAN). What we analyze concerning this initiative and offer proposals/contribution is on the subject of "Primitives" Definitions and Implementations on the Governance Interface and Federation Interface. We propose that in the COPAAN Blueprint the invocation dependency of some Primitives on other Primitives and operational state of an AN need to be researched and included in the specification. This needs to be considered because the state of an AN during operation may mean certain Primitives cannot be permitted to be invoked or successfully executed when the AN is

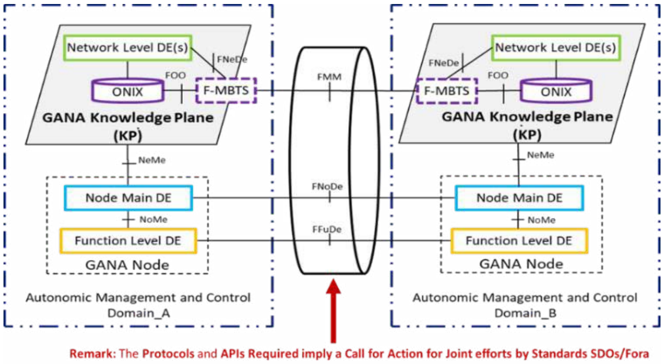

Figure 5: Federation of Autonomic Management & Control (AMC) Domains and Requirements for Protocols and APIs for Federation of AMC Operations for Cross-Domain Self-* (courtesy of ETSI TS 103 195-2)

in a particular state. Parameters to the Primitives is clearly a subject for research and further consideration in development of the COPAAN Blueprint. Security implications and solutions to address potential security problems also need consideration. The Multi-SDO Initiative under the auspices of the TM Forum has identified a new Industry Standardization Requirement that needs to be addressed urgently by the industry for the benefit of operating smart/intelligent (cognitive) systems of various classes across various sectors. Therefore, what is immediately needed is the development of a so-called standardized Blueprint of Common Operational Principles for Autonomic/Autonomous Networks (COPAAN). [3] presents a figure that illustrates a potential solution for implementing this required COPAAN blueprint standard. Robots and other classes of ANs need to be governed by humans through Common Operational Principles (COPAAN) such that their behaviour is governed and constrained by humans and not go out of control and cause harm. [3] presents the *Draft of a Conceptual Model of an AN's Key Operations-related Peripheral Interfaces* for derivation of COPAAN, namely the "*Governance Interface*" and "*Federation Interface*", *Primitives* and *Actors on the Interfaces,* as shown on Figure 3 and Figure 4, extracted from [3]. More details on the concepts presented in the two figures are found in [3]. Citing [2][3], the Multi-SDO initiative on ANs is meant to facilitate for information exchange among SDOs/Fora through coordination to enable to reduce duplication work, avoid standards collisions across SDOs/Fora, and identify gaps that need to be closed in standardization on ANs. Citing [2][3], the SDOs/Fora and Open-Source involved in the Multi-SDO include ETSI, GSMA, ONAP, NGNM, 3GPP SA5, CCSA, IEEE, IETF, ITU-T.

[2][3] present a proposal on "How to Build the Blueprint (COPAAN), the kinds of Inputs required for Developing the COPAAN, and the Outputs that should then be consumed by SDOs/Fora working on ANs". [3] provides a rationale as to why the industry now really needs a guide (COPAAN) on requirements an AN should fulfil in terms of its interaction with Human Operators, i.e., its Governance by the Human Operators, and the interaction of an AN with another AN or ANs in a Federation of ANs operations for the delivery of E2E services across ANs.

Figure 5 presents the illustration on Federation of Autonomic Management & Control (AMC) Domains and Requirements for Protocols and APIs for Federation of AMC Operations for Cross-Domain Self-* operations (courtesy of ETSI TS 103 195-2).

III. Uses Cases and Application of ETSI GANA Multi-Layer Autonomics and Multi-Layer AI Framework for Autonomic/Autonomous Networking (ANs) in 5G and 6G

In this section we provide an insight on availability of Frameworks that support Multi-Layer Autonomic Management & Control (AMC) that can now be used in implementing autonomics control-loops at various abstraction levels from within Network Elements/Functions (NEs/NFs) of a specific network architecture up into the realm of the management and control architecture associated with the network architecture. By providing insights on the availability of the standardized Uses Cases and Application of ETSI GANA Multi-Layer Autonomics and Multi-Layer AI/ML Framework (ETSI TS 103 195-2) for ANs in 5G and 6G, this helps researchers and innovators of industry grade autonomics to obtain the holistic picture on availability of frameworks through which to research and develop autonomics software (e.g., GANA DEs) that is deployable by the industry moving forward. The following are Use Cases (GANA instantiation cases now available): ETSI GANA autonomics onto BroadBand Forum (BBF) architectures (ETSI TR 103 473 V1.1.2); ETSI GANA autonomics onto 3GPP Backhaul and EPC Core Architectures (ETSI TR 103 404); ETSI GANA autonomics onto Heterogeneous Wireless Access Technologies using Cognitive Algorithms (ETSI TR 103 626); ETSI GANA autonomics in ITU-T IMT2020 Architectures (ITU-T Y.3324); ETSI GANA autonomics onto Ad-Hoc Mesh Networks (ETSI TR 103 495); Federated GANA Knowledge Planes (KPs) for Multi-Domain Autonomic Management & Control (AMC) of Slices in the NGMN® 5G End-to-End Architecture Framework (ETSI TR 103 747); Autonomic 5G Networks, powered by ETSI GANA Multi-Layer Autonomics & AI and IPv6 Capabilities & Extensions that enable to Build Autonomic Networks (ETSI TR 103 858); End-to-End AI-powered Autonomic Security Management & Control Across Multi-Domain 5G Networks (ETSI TR 103 857); Autonomicity and Self-Management in IMS architecture (ETSI TR 103 627); ETSI GANA autonomics in the TMForum ODA (Open Digital Architecture) Architecture.

IV. O-RAN RICs/rApps/xApps Framework, GANA Framework, and Hybrid-SON Framework Mappings

From our study we conclude that a *Framework for Harmonization* on complementary aspects and relationships that can be built among *Hybrid-SON Framework*, *ETSI GANA Multi-Layer Autonomics Framework*, and O-RAN *RICs/xApps/rApps*

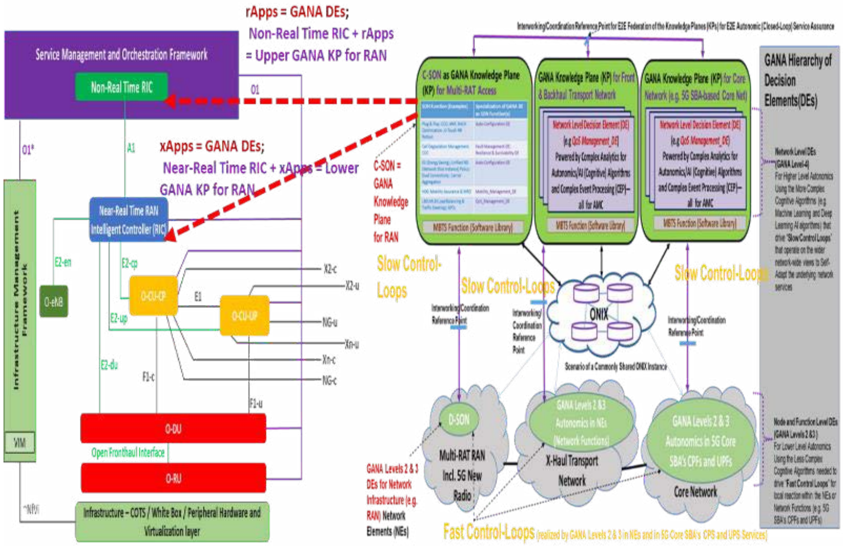

Figure 6: GANA Knowledge Plane (KP) for RAN through the RIC/xApps/rApps Framework for O-RAN case and through C-SON for the traditional RAN case; and E2E GANA KPs Platforms Federations

Framework, is required. Such a Framework should, among other attributes, capture aspects by which the three frameworks of *Hybrid-SON, ETSI GANA DEs, and O-RAN RICs/xApps/rApps* map to each other on common concepts and design and operational principles; where they complement each other; and on lessons learnt from Hybrid-SON and ETSI GANA Frameworks and techniques such as techniques for addressing Stability & Coordination of Autonomic Functions that can also be applied in the context of design and operations of O-RAN RICs/xApps/rApps as well. ETSI GANA is a Hybrid Model that enables to implement autonomics for various networks and network segments at specific Abstraction Levels for Autonomic/Self-Management Functionality. ETSI GANA guides and offers flexibility to implementers on the choice to implement certain autonomics as distributed software and associated algorithms within certain Network Elements/Functions (NEs/NFs), i.e., "*Micro Autonomics*", while being able to also choose to implement some autonomics algorithms as centralized algorithms in the *GANA Knowledge Plane (KP) Platform ("Macro Autonomics")* and interwork the two levels as described in ETSI TS 103 195-2. Hybrid SON Model is compatible with GANA. *Hybrid SON (C-SON (Centralized SON) & DSON (Distributed SON))* and their Interworking are considered as an implementation of the GANA Model for the RAN. Figure 6 is part of work started in ETSI in ETSI TR 103 858 in mapping the ETSI GANA Knowledge Plane (KP) concept for RAN to the *O-RAN RICs/xApps/rApps* framework. Figure 6 presents the idea of how a GANA Knowledge Plane for RAN can be implemented through the RIC/xApps/rApps Framework for O-RAN case and through C-SON for the traditional RAN case, and the fact that GANA KP Platforms for the various network segments/ domains need to follow Disaggregation principles requiring that they be federated to achieve collaborative E2E Autonomic Management & Control (AMC) Operations across domains as discussed in ETSI TR 103 747.

V. Overview of Requirements for KP Platforms Driven Networking: KP Platforms as Anchors for Federation of ANs Across Industry Sectors

In this section we provide a summary of Requirements we derive concerning the role that GANA Knowledge Plane (KP) Platforms should play as the anchors for Federation of Autonomic/Autonomous Networks (ANs) Across Industry Sectors. ***Why across Industry Sectors?*** This pertains to the fact that different kinds of organizations whose business profiles are associated with diverse sectors (e.g., public services sector, Government institutions sector, Healthcare sector, Automotive sector, Aerospace sector, Public 5G & beyond network service providers sector, private enterprises sector, Research Institutions sector, etc.) may find it desirable to avail their ICT assets such as Networks to be interconnected and federated with Networks belonging to organizations that may be required to deliver E2E services in an *agile and on-demand manor*. The incentive to avail assets like ICT networks to be enabled to be federated with other assets may be based on the desire of the owning organizations to share assets when and where needed and when available and monetize the lease of assets. The incentive could be based on the need to avail assets in situations that require emergency services for saving lives and societies in the event of natural disasters and pandemics like COVID that severely impact human mobility and movements patterns.

There are two aspects of Autonomic Management and Control (AMC) Federations that need to be considered in deriving the Requirements for GANA KP-to-KP federations:

1. **Type-A Federation:** Federations of GANA DEs' Autonomics operations based on DE's Autonomics Algorithms that may have been chosen to be implemented in a *Distributed* fashion (across NEs/NFs) such that the DEs involved collaborate to configure certain resources (Managed Entities (MEs)) in certain points in the network to achieve a network behaviour that can only be attained through the DEs' collaborations or exchange of information for the benefit of a certain larger scope of the network and services delivered by the portion of the network involved. ETSI TS 103 195-2 and Figure 5 illustrate the GANA levels at which the horizontal DE-to-DE collaborations/federations may be considered by AMC algorithms developers in such a case. While at GANA KP level the federations involve exchange of information and/or collaborations of KP DEs in negotiating best strategies to optimally configure/program, orchestrate, or troubleshoot resources within their network respective domains for the benefit of the Technology Domains involved such as Access Network, x-Haul Transport Network, Core Network, or Data Center Network as illustrated on Figure 6 and in ETSI TR 103 747. Such AMC Federations involving Technology Domains may be required to happen with the same Administrative Domain, e.g., within the same Communications Service Provider (CSP).
2. **Type-B Federation**: Federated AMC through GANA KPs across Administrative Domains that host various Technology Domains and associated GANA KPs. AMC federation at the level of the GANA KPs is likely to be the only level of AMC federations that

may be required across Administrative Domains, e.g., across CSPs.

Requirements pertaining GANA KP-to-KP Federations we study include the role of GANA KPs federations in *Composable Networks*, *Composable Services*, *Enablers such as Cloud Federations APIs*, *Autonomic Network Formations*, *How KPs Build Knowledge and can exchange Knowledge and negotiated operations/actions* for *Self-* AMC intelligence* across federated ANs, e.g., *Self-Optimizations, Self-Protection, Self-Diagnosis and Self-Healing, Self-Defense, etc*. The following are the Types of Requirements we identity and describe (order of the types does not mean priority of some requirements over the others):

1. **Type-1 Requirements**: KP support for the industry targeted COPAAN Blueprint' Governance and Federations Interfaces and associated Primitives
2. **Type-2 Requirements**: KP support of Mechanisms for Auto-Discovery by other KPs in a secure and trusted fashion
3. **Type-3 Requirements**: KP support of Mechanisms that enable the KP to collaborate with other KPs by way of federations that involve the KPs working together to instantiate and orchestrate networking resources to create dynamically *Composable Networks* built using various technologies required to deliver services to humans and machines as may be needed *on-demand*, and with the KPs working together to destroy or delete the networks and or services when no longer needed.
4. **Type-4 Requirements**: KP support of Mechanisms that enable the KP to collaborate with other KPs by way of federations that involve the KPs working together to instantiate and orchestrate network services to create dynamically *Composable Services* using network resources or network instances that already exist and are under the management and control responsibility of their respective KPs.
5. **Type-5 Requirements**: KP support for Enablers for Federations such as Cloud Federations API defined by IEEE Std 2302™-2021 that was originally developed by NIST [9] and was further developed into IEEE as a standard. Such APIs are more relevant for *Type-B Federation*.
6. **Type-6 Requirements**: KP role in *Autonomic network and connectivity formations and orchestrations* in response to detected situations and predicted situations, and/or agile service innovation and delivery across industries in a federated fashion
7. **Type-7 Requirements**: KP support for Mechanisms and Techniques for supporting *Type-A Federation*. This implies support for Protocols and APIs for federations as depicted in Figure 5.
8. **Type-8 Requirements**: KP support for Mechanisms and Techniques for supporting *Type-B Federation*. This implies KP support for Enablers for Federations such as Cloud Federations API defined by IEEE Std 2302™-2021 that was originally developed by NIST [9] and was further developed into IEEE as a standard; and also, KP support for "*Needs*" defined by IEEE INGR Future Networks Systems Optimization Chapter [3] that pertain to Federations across administrative domains.
9. **Type-9 Requirements**: KP support of Mechanisms and Techniques for Building Knowledge and ability to exchange Knowledge and enter negotiations with other KPs on operations/actions that KPs should execute for Self-* AMC intelligence across federated ANs, e.g., *Self-Optimizations, Self-Protection, Self-Diagnosis and Self-Healing, etc.*

VI. Conclusion and Further Work

The paper provides an analysis of the aspects of relevance to the broader picture of ANs in standardization efforts, multi-layer autonomic systems design and operational principles, federation and governance of ANs, progress in standards, so as to provide contributions on what needs to be complemented to ongoing efforts in standardization groups. But the major contribution of this paper is on the aspect of *Requirements for Knowledge Plane (KP) Platforms Driven Networking, by which KP Platforms play the role of anchors for Federation of Autonomic/Autonomous Networks (ANs) Across Industry Sectors*. Whereby we consider that KP Platforms should be the anchor Functional Entities through which Federation and Governance of ANs should be achieved such that the federated ANs deliver end-to-end services in an *agile and o-demand manor* in fulfilling various dynamic communication services needs by humans and machines, and through which resilience and survivability of ICT network infrastructures and services should be achieved through collaborative actions and intelligence of the GANA KP Platforms. Requirements we study include the role of KPs in *Composable Networks*, *Composable Services*, *Enablers such as Cloud Federations APIs*, *Autonomic Network Formations*, *How KPs build Knowledge and can exchange Knowledge and negotiated operations/actions* for *Self-* AMC intelligence* within and across federated ANs, e.g., *Self-Optimizations, Self-Protection, Self-Diagnosis and Self-Healing, Self-Defense, etc*.

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