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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

ETSI PoC* Demo-2 *on 5G Network Slices Creation, Autonomic & Cognitive Management and E2E Orchestration; with Closed-Loop(Autonomic) Service Assurance of Network Slices; using the Smart Insurance IoT Use Case

White Paper No.2
(of a series of White Papers expected from the ETSI PoC)

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ETSI TC INT AFI WG 5G POC

Table of Contents

Other Complementary White Papers:

- ***White Paper No.1:*** ***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***

- ***White Paper No.3:*** ***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***

Executive Summary

ETSI (European Telecommunications Standards Institute) TC INT/AFI Working Group (WG) is running a PoC (Proof-Of-Concept) on ***5G Network Slices Creation, Autonomic & Cognitive Management & E2E Orchestration; with Closed-Loop (Autonomic) Service Assurance for the IoT 5G Slices (using Smart Insurance Use Case)***.

ETSI TC INT/ AFI WG has recently published the de-facto standard on the GANA (Generic Autonomic Networking Architecture) Reference Model—An Architectural Reference Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services [2]. ETSI TC INT/ AFI WG has since established that E2E Autonomic (Closed-Loop) Service Assurance shall be achievable through the *Federation of GANA Knowledge Planes (KPs)* that implement components for autonomic management and control (AMC) intelligence for specific network segments and domains. Autonomics by the GANA Knowledge Plane (KP) for a particular network segment/domain is complemented by lower level autonomics introduced in Network Functions(NFs) of the particular network segment under the responsibility of the KP, such that the KP policy-controls the lower level autonomics introduced in NFs. The E2E federation of KPs for the various network segments/domains and their policy-controlling of lower levels autonomics in the NFs of their respective network segments, enable the complementary multi-layer autonomics to realize Holistic Multi-Domain State Correlation and resources programming by the GANA KPs for the network segments/domains such as the Access, X-Haul (particularly Fronthaul and Backhaul), and Core Networks, etc.

The question of how to implement GANA-defined autonomic manager components (called autonomic functions) in physical network elements/functions (NEs/NFs) and Virtualized Network Functions (VNFs) and complementing them 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), is being answered by ETSI TC INT/AFI WG Specifications such as ETSI TR 103 404, ETSI TR 103 495, and ETSI TR 103 473. NOTE: The ETSI GANA Model and associated concepts are briefly described later in the in this paper, to help readers understand the PoC's objectives.

Open Source is now playing a key role in implementing some ICT standards, and the industry has reached the consensus that Standardization activities in the Telecommunications Industry and Open Source Projects are supposed to work with each other complementarily to leverage the best of both worlds and help the industry to deploy interoperable products—thanks to standards, and achieve accelerated pace and openness for innovation—thanks to open source. ONAP and other open source products can be used to implement components that fulfil GANA requirements on design and implementation of GANA Knowledge Planes for specific network segments. Therefore, the industry and implementers of autonomic management and control software that is based on the ETSI GANA standard (ETSI TS 103 195-2), require a guidance on ***ONAP Mappings to the ETSI GANA Model, how to use ONAP Components to Implement GANA Knowledge Planes, and how to advance ONAP for Implementing ETSI GANA Standard's Requirements***. As C-SON (Self-Organizing Networks) software for the RAN (Radio Access Network) is a way to implement the GANA Knowledge Plane for the RAN, this paper also seeks to provide guidance on how to implement a ***C-SON – ONAP Architecture*** *(i.e. use of ONAP in implementing C-SON and evolving ONAP accordingly) based on a real C-SON implementation presented in this paper*. The industry (as represented in various SDOs such as TM Forum are now adopting the ETSI GANA Model concepts (such as GANA Knowledge Plane concept) into their E2E management and control frameworks [6] [18].

Readers are encouraged to follow the developments, progression and the results of the ETSI 5G PoC(https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals)[3], as there are plans for a series of Demos planned to cover various aspects of the overall PoC in the timeframe 2018/2019 and beyond). For more background information on what has been achieved and addressed so far by the "**ETSI PoC on GANA in 5G Network Slicing**" and the future Demos in plan, readers can access Reports, Demo sheets and Slides at: https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals .

The PoC Consortium is not "closed-consortium", and welcomes new members in the course of the PoC duration, which goes beyond 2018/2019 timeframe. Contact details are given at the end of this White Paper, for those interested in the PoC results or joining the Consortium. This White Paper is based on Demo-2 of the 5G PoC and complements other White Papers that are based on Demo-2 and other Demos of a series of Planned Demos on various aspects of the overall ETSI 5G Network Slicing PoC, as more Demos are expected in the duration of the PoC over 2018/2019.

1. Problem Statement addressed by Demo-2 of the ETSI 5G PoC

1.1. Overview

Within the Digital Transformation strategy, in order for the digital business ecosystems under deployment by Service Providers (as they are becoming Digital Service Providers) to be successful, they must be profitable and must create value at the touch points between the stakeholders involved in those Business ecosystems and must meet the new way of consuming digital services including Network Slices the customers (Verticals) are prescribing.

Each Digital Service / 5G Network Slice Instance is unique and versatile at the same time, meaning its characteristics could be dynamically changed over time according to the consumer needs from design, operations, charging, and billing processes perspective. In this regard, Digital business ecosystems and their underling Digital Architectures must support highly disaggregated and modularized capabilities to allow delivering the required customized Network Slice instances. This is the first industry consensus but there is a need to go steps beyond.

The second industry consensus within this major shift in the Digital Service Providers space and in the Vendors / Suppliers space is the evolution of current networks to the so-called "smart networks of the future" which are characterized (from Service Assurance perspective of Network Slices for example) by the need to be operated based on principles of dynamically adaptive Automated and Autonomic Management & Control (AMC) of networks and services (aka "*autonomics*"). AMC is aimed at replacing the increasingly complex and error-prone manual and static management and optimization of networks and services, as such manual and static management approaches are inacceptable in the Service Assurance process of Network Slices. This means, the disaggregation and modularization characteristics should also be built-in by design in the AMC's hierarchical autonomic decision-making framework and its associated hierarchical "Decision-making Element (DE) components" themselves (which must be viewed as Software Logic/ Algorithms) and could be implementable as standalone processes (e.g. as *microservices*) or having some (of such logics) combined together to run/execute as a single process at run-time. Moreover, Digital Service Providers seek to view Autonomic Decision-making Element logics (modular "autonomic manager components") as Run-Time (re)-Loadable / replaceable software (SW) modules and want to be given the ability to (re)-load into the network and management and control realm the best-in-class autonomic Decision-making Element (DE) components that exhibit better cognitive algorithms for autonomics (closed-loop operations) over time, from any supplier and why not from a Marketplace if created by an open source community (as *Acumos* did for AI (Artificial Intelligence) components) or any recognized industry support body. Service Providers, Enterprise and telecom networking products vendors/suppliers are joining efforts in developing Open Source for Telecoms and Enterprise ICT Networks, and the efforts are yielding results, e.g. with the ONAP open source project [9], OPNFV [12], OSM [15], and the many other emerging open source projects. The question of how to implement ETSI GANA Standard's Requirements using ONAP and how ONAP can be evolved to implement requirements for AMC that derive from GANA, is the focus of this White Paper, while presenting a "C-SON – ONAP Architecture" real implementation as illustration of how a GANA Knowledge Plane for RAN (namely C-SON (Centralized Self-Organizing Network) software) can be implemented using ONAP and extensions required thereof. A reflection is also given in this paper, on how other open source products can be considered in implementing the integration framework for ETSI GANA and other networking paradigms such as SDN (Software-Defined Networking), NFV (Network Functions Virtualization), Big-Data Analytics for AMC, and E2E Orchestration.

1.2. Background of the ETSI 5G PoC

In order to operate 5G Networks and deliver 5G Network Slices, the Telecom Operator must be equipped with a GANA-compliant ***Framework for E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices***. E2E Autonomic Slice Assurance shall be achievable by way of Federation of GANA Knowledge Planes (KPs) for network segments/domains such as RAN (C-SON), MEC (Multi-Access Edge Computing) site, Front-/Backhaul and Core Network, and complemented by lower level autonomics in Network Elements (NEs) or Network Functions (NFs). This complementary interworking of low level autonomics in NEs/NFs and autonomics in the outer realm of the so-called GANA Knowledge Planes as well as the federated

collaboration of the Knowledge Planes, helps to achieve "holistic E2E multi-domain state correlation and dynamic/adaptive programming" of network resources (managed entities) by the GANA KPs (KP for RAN, KP for Data Center (DC), KP for MEC (Multi-Access Edge Computing), KP for Fonthaul & Backhaul, and KP for the Core Network) to deliver E2E Autonomic Service Assurance of Network Services across network segments/domains. A decision on choosing to have a Knowledge Plane designed and implemented for a specific network segment (or domain) rather than having a single large Knowledge Plane that covers multiple network segments may follow various incentives (based on technical or administrative or even business models reasons). GANA autonomics is the enabler for the realization (implementation) of "***Self-Driving Networks***" that are "***Self-Aware***".

1.3. The Related Problem addressed by Demo-2 and continues to be further addressed in the PoC

One of the ***Requirements*** the industry must address in order for Service Provider to be able to implement the desirable *Framework for E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices* is on encouraging industry to develop products for autonomic service assurance by **using ONAP Components to Implement GANA Knowledge Planes and Advancing of ONAP for Implementing the ETSI GANA Standard's Requirements** (i.e. answering the question of **how ONAP can be evolved to implement requirements for AMC that derive from GANA).** An example case for ONAP for GANA Knowledge Planes implementation is a "C-SON – ONAP Architecture" real implementation by Cellwize presented in this paper as illustration of how a GANA Knowledge Plane for RAN (namely C-SON) can be implemented using ONAP and extensions required thereof. On the other hand, it is critically important to provide guidance to the industry on how ONAP framework can be mapped to the ETSI GANA Model, since the GANA has emerged as the standard that provides a holistic framework on how to introduce autonomics in network architectures and their associated management and control architectures (various GANA instantiations onto different types of network architectures and their associated management and control architectures already exist (e.g. ETSI TR 103 473, ETSI TR 103 404, and other ETSI TRs) .

1.4. How the White Paper is organized

In order to understand the concepts and network operators' requirements addressed by Demo-2 (of a series of Demos planned for the 5G PoC), this white paper first gives a brief introduction to the ETSI GANA Model and the recently published ETSI Standard (ETSI TS 103 195-2) [2], and then moves on to describe the GANA principles for Autonomic Management and Control (AMC) of networks and services (including the concept of autonomic service assurance and the GANA Knowledge Plane). The paper also presents the value of Multi-Layer Autonomics and the integration of the GANA Knowledge Plane with Orchestrators, SDN Controllers, Big-Data for Autonomic (closed-loop) Service Assurance, and OSS/BSS systems(Operations Support System/Business Support System). It then presents the following aspects:

- *Overall ONAP to GANA Mappings and How ONAP can be used to implement GANA Knowledge Plane Components*
- *An illustration on using ONAP Components to Implement GANA Knowledge Planes and Advancing ONAP accordingly—using a "C-SON – ONAP Architecture" implementation by Cellwize as an illustration on GANA Knowledge Plane for the RAN (Radio Access Network) and C-SON role in 5G Network Slice Assurance*
- *Using ONAP with other Open Source Products to implement GANA Knowledge Planes for other Network Segments/Domains other than the GANA Knowledge Plane for RAN (C-SON)*
- *The value of Federation of GANA Knowledge Planes for E2E Autonomic (Closed-Loop) Service Assurance across various network segments/domains*
- *Vendors' Business View of the Overall 5G PoC in Supplying ONAP based GANA Knowledge Planes Software/Platforms for E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices*

1.5. Summary of aspects that are covered in other complementary White Papers from the ETSI 5G PoC

White Paper No.1 covers the following aspects:

- *Service Provider's Requirements for a Framework for E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices.*
- *Smart Insurance Providers as Key Requesters and Consumers of 5G Network Slices Delivered by Service Providers in fulfilment of Slice Requests*
- *QualyCloud Capabilities that address the Requirements of Key Requesters and Consumers of 5G Network Slices that should be delivered by Service Providers in fulfilment of Slice Requests received from the external slice requesters via self-care portals*
- *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*
- *How Cellwize 5G SON capabilities address the outlined Telecom Operators' Requirements tailored to Telecom Operators' desired Framework for E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices.*
- *The Four Applications considered in the Overall 5G PoC's Network Slicing Use Cases*
- *Technical view of the Overall 5G PoC*
- *Summary of Further Plans on Demo series planned for the overall 5G PoC in the timeframe 2018/2019 and beyond*

White Paper No.3 covers the following aspects:

- *Service Provider's Requirements for Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring as Cost-Effective approach to implementing adaptive traffic monitoring solutions suitable for 5G*
- *The art of Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring and Feeding of Knowledge into the GANA Knowledge Plane for Autonomic Service Assurance of 5G Network Slices; and Orchestrated Service Monitoring in NFV/Clouds*
- *Framework for Dynamic Probing for Orchestrated Assurance and the Integration/Convergence of Autonomic Service Assurance with Orchestrated Assurance for Newly Instantiated Network Services*
- *Capabilities of Big Switch Networks for Programmable Traffic Monitoring Fabrics that meet the Outlined Telecom Operators' Requirements in line with the ETSI GANA Framework Principles*
- *"Knowledge Plane-Driven" Orchestration—based on Business Goal Incentives or Autonomic Remediation Strategies Execution by the KP; and Selective Multi-Layer Programming Targets by KP Autonomics*

2. Brief introduction to the ETSI GANA Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services

ETSI TS 103 195-2 [2] defines the concept of Autonomic Manager element (called a "**Decision-making-Element" (DE)** in the GANA terminology) as a functional entity that drives a control-loop meant to configure and adapt (i.e. regulate) the behaviour or state of a Managed Entity (i.e. a resource)—usually multiple Managed Entities(MEs). The ETSI GANA Standardized Framework for AMC (ETSI TS 103 195-2) defines an Intelligent Management and Control Functional Block called GANA KP that is an integral part of AMC Systems that provides for the space to implement complex network analytics functions (cognitive algorithms for autonomics) performed by interworking Modularized and specialized DEs. The KP DEs run as software in the Knowledge Plane and drive *self-* operations such as self-adaptation, self-optimization, self-monitoring* objectives for the network and services by programmatically (re)-configuring Managed Entities (MEs) in the network infrastructure through various means possible: e.g. through the NorthBound Interfaces available at the OSS, Service Orchestrator, Domain Orchestrator, SDN controller, EMS/NMS, NFV Orchestrator, etc.

The GANA KP consists of multiple modularized DEs. In contrast to non-modularized management systems, each DE is expected to be a module (as atomic block) and that it should address a very specific "management or control domain (scope of management or control aspects/problems)" such that it can run as a "micro service".

Examples of autonomic managers (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*. Autonomic Manager

components (DE components) of the GANA KP are "macro" autonomic managers that drive logically centralized and network-wide but slow control loops that operate in "slower timescale" than similar control-loops introduced to run in Network Elements (NEs) and operating as "faster timescale control-loops (i.e. the so-called fast control-loops)". GANA instantiations such as ETSI TR 103 473, ETSI TR 103 404, provide insights on the question of "*what types of DEs can be introduced in certain types of Network Elements (NEs) of a network architecture*". Macro autonomic managers (GANA KP DEs) should be complemented by "micro" Autonomic Manager components (DEs injected into NEs) that can be introduced in the Network Elements (physical or virtualized) for driving local intelligence within individual network elements to realize "fast control-loops" in network elements. Macro autonomic managers (GANA KP DEs) policy-control the "micro" autonomic managers (GANA DEs in NEs—i.e. the so-called GANA Level-2 and Level-3 in the ETSI TS 103 195-2).

ETSI TC INT AFI WG's work on E2E autonomic networking involves introducing self-manageability (autonomics) properties (*e.g. self-configuration, self-diagnosis, self-repair, self-healing, self-protection, self-awareness, etc.*) within network nodes/functions themselves and also enabling distributed "*in-network*" self-management within the data plane network architectures (and their embedment of "thin control planes"). This low level intelligence (autonomics) achievable by so-called "GANA DEs" that should be instantiated to drive fast control-loops within network nodes/elements and to drive horizontal self-adaptive collaborative "in-network" behaviour involving the collaboration of certain autonomic nodes is also called "*Micro level"* autonomics ("fast control loops"). The low level autonomics shall be complemented and policy-controlled (governed) by higher level autonomics ("slow control loops") (at "*Macro level*") achievable and driven by higher level "GANA DEs" responsible for network-wide and logically centralized autonomic management and control of networks and services. At "Macro level", the autonomics paradigm (control loops) is introduced outside of network elements, in the outer, logically centralized, management and control planes architectures of a particular target network. This "realm" for implementing the much more complex, cognitive and analytics algorithms (including Artificial Intelligence (AI) Algorithms) for autonomics that operate on network-wide views is called the GANA Knowledge Plane (GANA KP). 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 (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 & 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.

The "GANA" reference model combines perspectives on GANA DE ("Micro-Level" autonomics (defined by the so-called GANA levels-1 to Level-3 illustrated in Figure 1)) and the interworking GANA KP DE (with "Macro-Level" autonomics (realized by the GANA Knowledge Plane)) as well as the responsible Functional Blocks and Reference Points that enable developers to implement autonomics software, with all perspectives combined together so as to capture the holistic picture of autonomic networking, cognitive networking and self-management design and operational principles. This ETSI GANA Framework is illustrated in Figure 1.

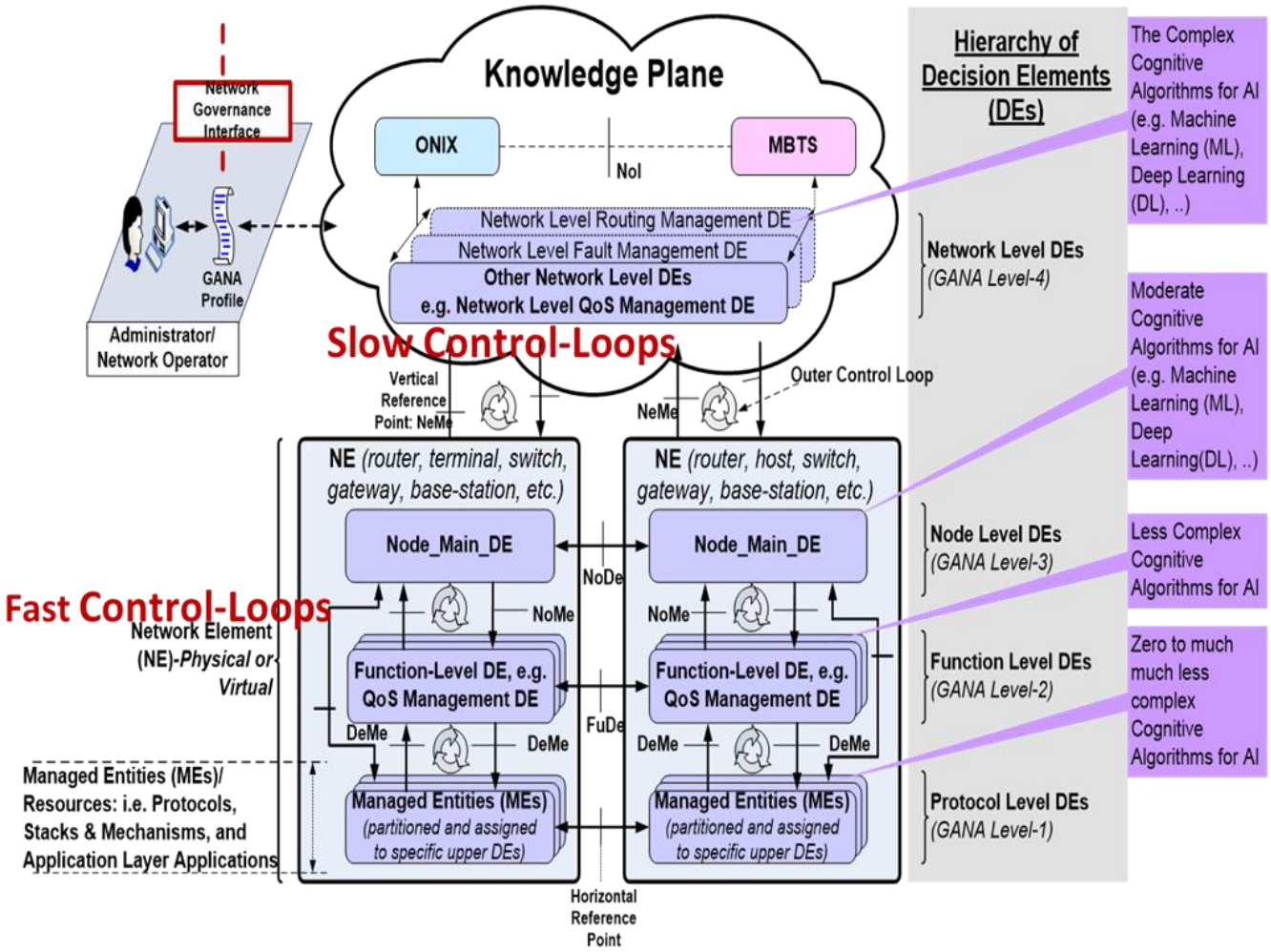

Figure 1: ***Snapshot of the GANA Reference Model and Autonomics Cognitive Algorithms for Artificial Intelligence (AI)***

3. GANA Decision-Elements/Engines(DEs) as "*AMC Services*" that dynamically manage and control specific Managed Entities (MEs) embedded within NEs/NFs

DE algorithms (including Artificial Intelligence (AI) Algorithms) for autonomics and overall logic, which determine the DE's intelligence on when a DE adaptively decides to (re)-configure its assigned (by design) Managed Entities (MEs), are expected to vary according to the DE vendor/supplier. As such, algorithms (just like in the case of SON (Self-Organizing Networks) Algorithms) cannot be standardized as they are the means to provide for DE vendor innovation and differentiation as described in ETSI White Paper No.16 and ETSI TS 103 195-2[2]. Decision Elements (DEs) are characterized as follows: Centralized Control Software Logics (those meant to operate in the GANA Knowledge Plane), and Distributed Control Software Logics (those meant to operate in NEs/NFs). The two types of DEs operate in different time-scales (as described in ETSI TS 103 195-2) but interworking harmoniously in realizing autonomic behaviors (*self-configuration, self-optimization, and other self-* operations DEs perform on their Managed Entities (MEs)*) [2]. DEs may be "loaded or replaced" in NEs in general and in the GANA KP, bringing about the notion of "Software-Driven or Software-Empowered Networks", as DEs that exhibit better Algorithms and Intelligence (Cognition) may continuously be innovated by DE vendors/suppliers. The following points characterize the value of DEs introduced into any network architecture and its associated management and control architecture:

1. **DE specialization:** The DE concept should be specialized for a specific type of autonomic management and control (AMC) domain, e.g. *Autonomic QoS-management & control domain, Autonomic Security-management & control domain, Autonomic Mobility-management & control domain, Autonomic Fault-management domain, Autonomic Resilience and Survivability management & control domain, Autonomic Service & Application management domain, Autonomic Forwarding-management & control domain, Autonomic Routing-management & control domain, Autonomic Monitoring-management domain , Autonomic Generalized Control Plane management & control domain*. ETSI TS 103 195-2 defines a set of such domains and associated DEs (which can be viewed as specialized AMC services at run-time) that can be instantiated into Network Functions (NFs) of a network architecture (such as a backhaul or core network architecture) and the associated management and control systems realm of the network architecture. Such DEs should be injected into a Network Function or injected within a service associated with a Network Function (NF). ETSI TS 103 195-2, and GANA instantiations such as ETSI TR 103 473, ETSI TR 103 404, provide insights on the question of "*what types of DEs can be introduced in certain types of Network Elements/Functions (NEs/NFs) of a network architecture*". Any DE in the autonomic network node (network element/function) of the network infrastructure should have a mirror Network Level DE in the GANA Knowledge Plane for the particular network segment which operates on network wide views and shall policy-control the corresponding DE in the node (NE/NF). Managed Entities (MEs) should be autonomically orchestrated and/or configured by the responsible DE as part of the overall functionality for the operation of the Network Element. The human network operator's automated management tools need to have the ability to govern any DEs i.e. configure and control any behavior of any DE and its mode of operation ("open-loop" or "closed-loop"). Therefore, any DE should be governable to be configured to operate in Open-Loop or Closed-Loop Mode, and to consume policies and other inputs provided to it by network operator's automated management tools used by the human operator. A mapping table between each types of a DE and its associated MEs is specified in ETSI TS 103 195-2 to enable DE developers to innovate DEs and their associated "vendor-differentiator" DE algorithms.
2. The interaction and coordination between DEs should take into consideration the Hierarchical nature of control loops and peer to peer DE reference point defined in ETSI TS 103 195-2[2]. A mapping table between each DE and its required collaborative DEs should be specified per "AMC objective" by DE implementers to allow the integrations of a chain of DEs provided by different DE suppliers
3. Like any functional entity, a DE should be managed, and operations and primitives needed to manage a DE that are defined in ETSI TS 103 195-2[2] should be implemented by a DE. The operational goals of a DE should be clearly defined, even without explicitly exposing the algorithm of the DE.
4. DEs should be designed and linked (associated with) a specific Network Domain/Segment, Network Architecture Layers and their outer Management & Control Architecture Layers associated with a specific Network Domain/Segment. Network domains can be access network, edge, x-haul (particularly fronthaul and backhaul) network, core network, transport network, data center network or other types of network domain. Network Architecture Layers include the GANA Levels (network-level, node-level, function-level, protocol level) defined by the GANA Model. Management & Control Architecture Layers include the GANA KP (GANA network-level) layer and the Business and Service Management Layers that provide inputs that drive and govern the Knowledge Plane's autonomic operations.
5. E2E Autonomic Service Assurance of E2E Network Services (including 5G Network Slices) shall be achievable through the ***Federation of GANA KPs for specific network segments and domains***, and ***complemented by lower level autonomics in Network Functions(NFs),*** for a "*Holistic E2E Multi-Domain State Correlation and adaptive resources (re)-programming*" by the **GANA KPs** for ***Access***, ***X-Haul/Backhaul***, and ***Core Networks (as illustrated later).*** *The scope of Federation of Knowledge Planes may be extended to cover other domains beyond the core network, such as a Data Center Network hosting some Telco-Cloud Network Functions or even IT Applications.* Service Providers seek to deploy ***Framework for E2E Autonomic (Closed-Loop) Service Assurance for Network Services*** as illustrated later. ETSI TS 103 195-2 provides guiding principles that help implementers to implement Federation of GANA Knowledge Planes across multiple domains (including administrative domains). Within the same Knowledge Plane of a particular network segment (e.g. access or core network) DEs exchange knowledge and synchronization or coordination messages directly among each other. Knowledge acquired in different network domains or layers such as the GANA Knowledge Plane Layer may be exchanged between the domains and layers through the ONIX system as illustrated later along with illustration of federation of Knowledge Planes for various domains.
6. A DE service (the DE itself), particularly for the case of the GANA KP DEs, can be replaced/upgraded/controlled by the network operator at any time during the operations lifecycle of the network. This is because DEs maybe "loaded or replaced" in NEs/NFs and in the GANA Knowledge Plane, bringing about the notion of "Software-Driven or Software-

Empowered Networks", as DEs that exhibit better Algorithms and Intelligence may continuously be innovated by DE vendors/suppliers. Figure 1, illustrates the varying degree of complexity in Artificial Intelligence (AI) Algorithms for autonomics as we traverse upwards along the GANA Decision Elements (DEs) Hierarchy for self-management (autonomics) abstraction layers (more details on this subject are found in ETSI TS 103 195-2).

7. Network operator may develop or select on a marketplace some of the DEs according to the business needs of the network operator. Network operator should be able to test, certify, trust, validate any DEs.

8. ETSI TS 103 195-2 provides guidance on how legacy management systems could be used in parallel with Self-management DEs implemented by the GANA Knowledge Plane during the transition phase from the legacy systems, in order to smoothly upgrade legacy management by interworking them with the "self-management enabling" Knowledge Plane.

NOTE: ETSI TS 103 195-2 contains more details on guidance to how DEs can be designed and implemented at run-time, e.g. how DEs within an NE could be implemented as standalone processes at run-time or having some DEs within an NE merged to run as a single process at run-time.

4. Collaboration/Coordination of Autonomic Functions (DEs) through synchronization of actions/policies on programming their corresponding Managed Entities (MEs)

There are policies or actions of DEs that require Collaboration/Coordination of DEs through synchronization of actions on programming their corresponding MEs. Some coordination/synchronization may involve only "a set" of DEs (not all) in the KP or an NE and some may require the coordination/synchronization of "all" the DEs. The figure below illustrates this aspect of the need for Collaboration/Coordination of DEs. This subject is linked to the topic of addressing stability of control-loops for optimal behavior and state of operation of the autonomic network and its associated autonomic management and control operations. ETSI TS 103 195-2 [2] covers this subject of coordination of DEs and achieving stability of control-loops in GANA in much more detail.

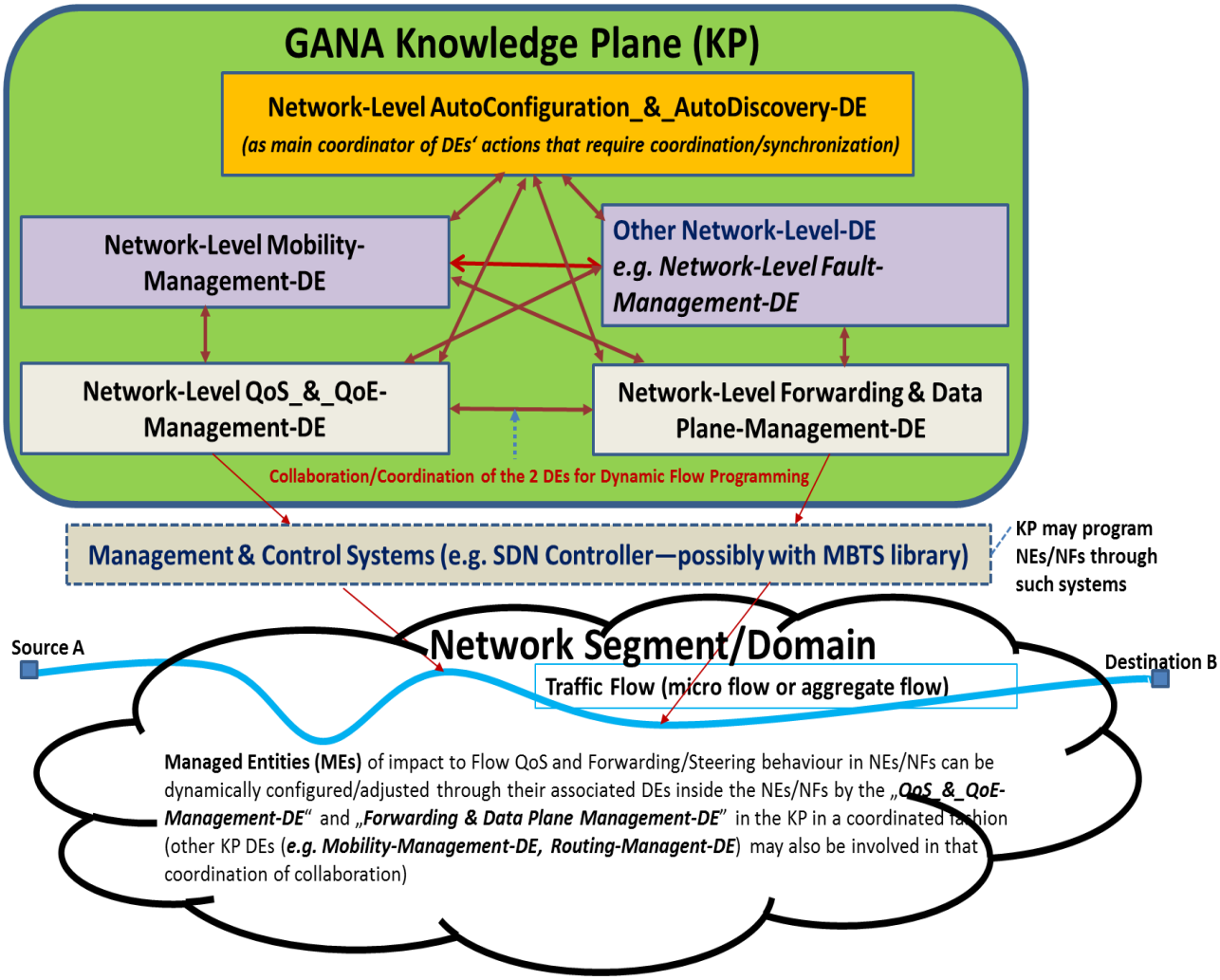

Figure 2: Need for collaboration or coordination of Autonomic Functions (DEs) on certain actions or aspects that are better addressed through collaboration/coordination

5. Multi-Layer Autonomics and the integration of the GANA Knowledge Plane with Orchestrators, SDN Controllers, and OSS/BSS systems

The diagrams below illustrate the integration of GANA Knowledge Plane with other management and control types of components/systems, as well as multi-layer autonomics (more details on this subject can be found in ETSI White Paper No.16 and ETSI TR 103 473), i.e. the abstraction levels at which Autonomic Functions (i.e. Decision Elements (DEs)) can be implemented (as illustrated on Figure-1, regarding the ETSI GANA Model). The Figure 3, illustrates the notion of multilayer autonomics, i.e. the introduction of DEs and associated control-loops at the various layers of network infrastructure and its associated management and control architectural hierarchy. The value of multi-layer autonomics and how the autonomics at each layer complements autonomics at another layer is described below.

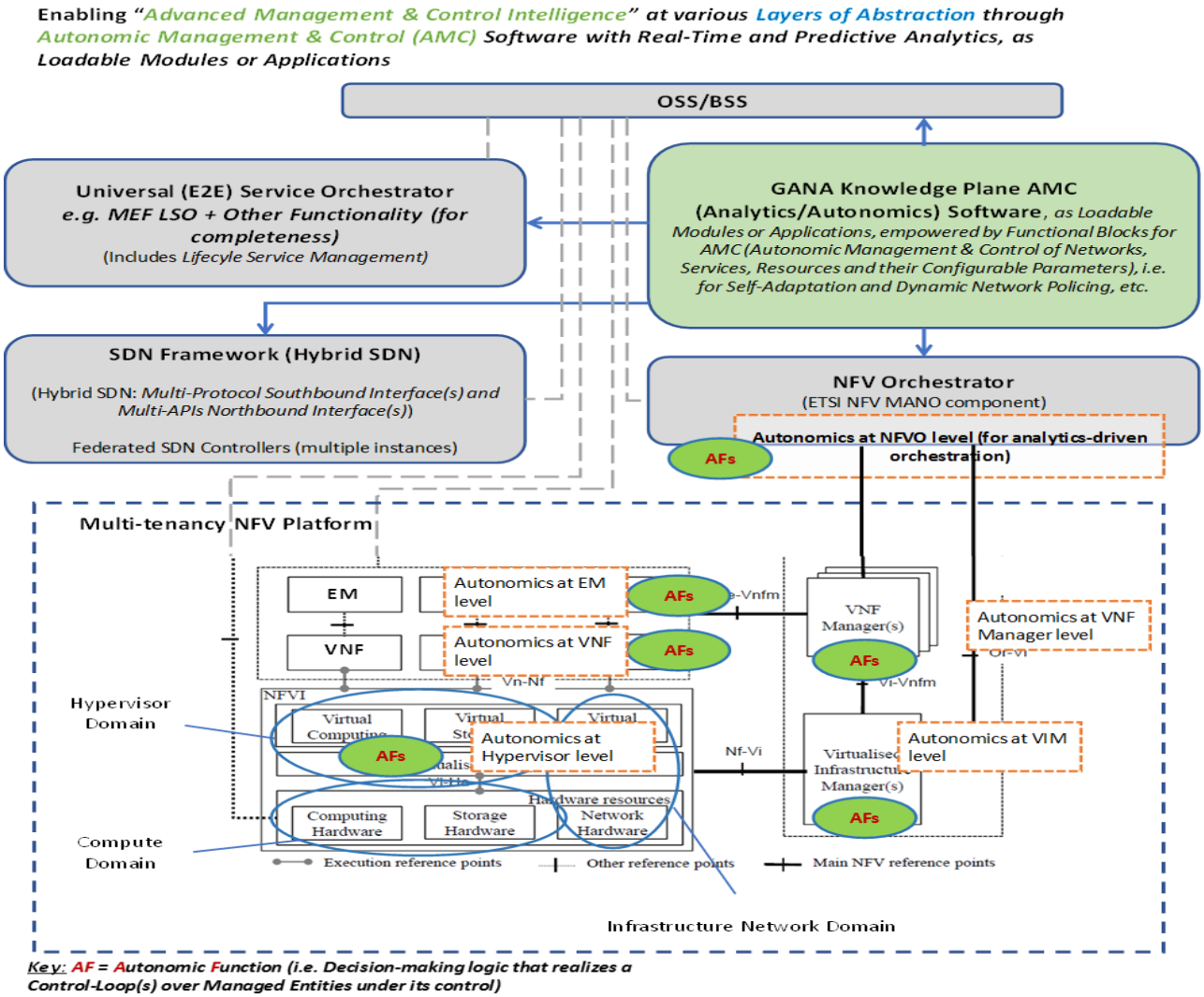

Figure 3: ***Multi-Layer Autonomics and the integration of the GANA Knowledge Plane with Orchestrators, SDN Controllers, NFV, and OSS/BSS systems***

The **Figure 4** illustrates the Unified/Integration Architecture for ETSI GANA Knowledge Plane (KP), SDN, NFV, E2E Orchestration, Big-Data driven analytics for AMC, OSS/BSS, and is covered in more detail in ETSI White Paper No.16. NOTE: Certain Big-Data Applications for Analytics-Driven Orchestration and Management and Control can be implemented as part of Knowledge Plane DEs' logics themselves rather than outside DE logics as external applications that interact with KP DEs. As such, in reference to the integration of the GANA Knowledge Plane with Big-Data Applications for AMC as shown on Figure 4 below, such Big-Data Applications (e.g. Optimization Apps) should interwork with the KP or can be invoked by KP— if such Applications couldn't be implemented as integral parts of the KP (either as embedded parts of DE logic or as Analytics Modules commonly shared by the multiple KP DEs).

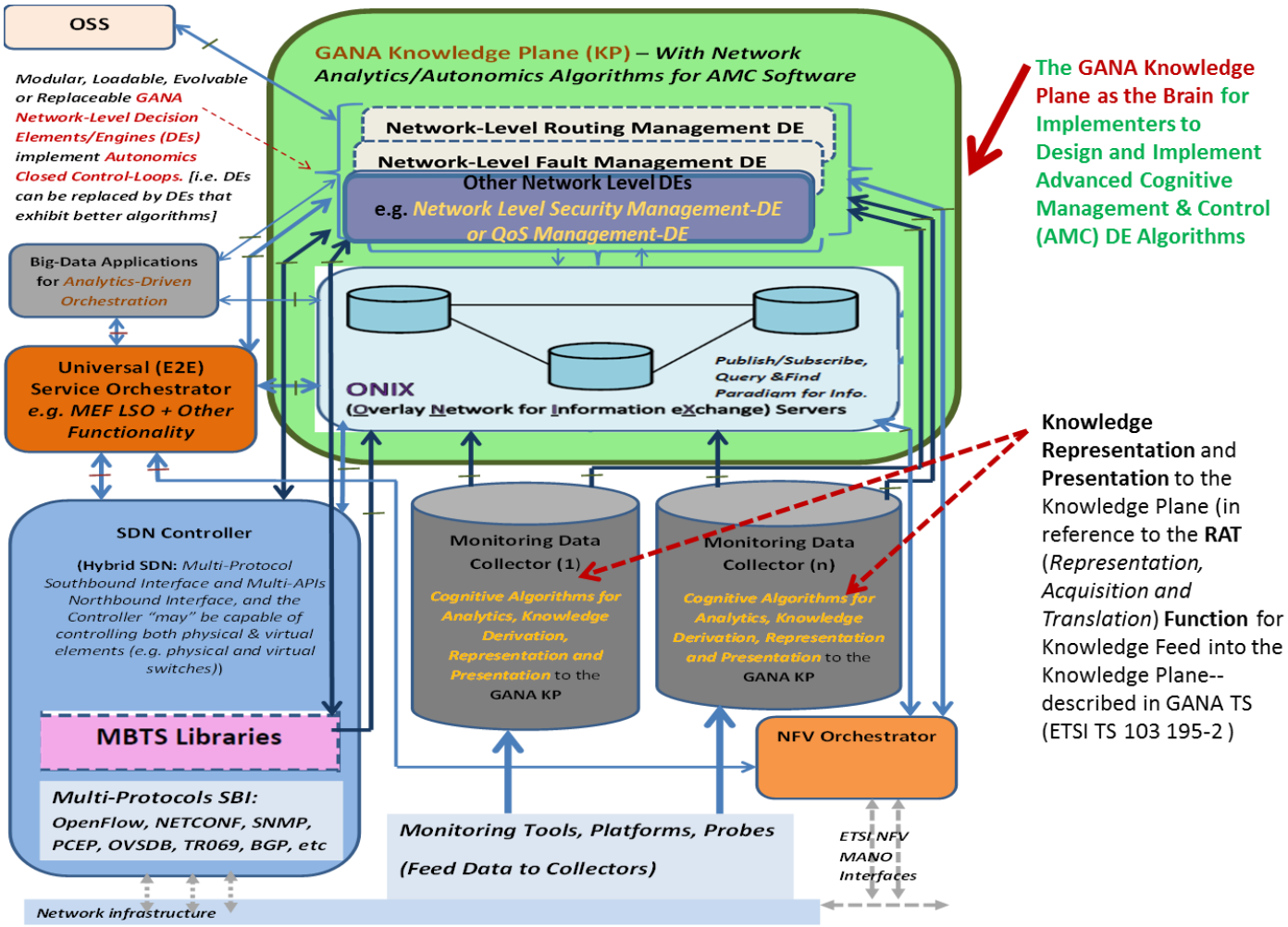

Figure 4: ***Unified/Integration Architecture for ETSI GANA Knowledge Plane, SDN, NFV, E2E Orchestration, Big-Data driven analytics for AMC, OSS/BSS***

ETSI TS 103 195-2 [2] describes the way to interwork the GANA Knowledge Plane with Traditional Network Management Systems and with other management and control systems such as OSS, Service Orchestrator, Domain Orchestrator, SDN controller, EMS/NMS, NFV Orchestrator, etc.

The GANA Knowledge Plane is an integral part of Management and Control Systems that provides for the space to implement complex network analytics functions performed by interworking Modularized Autonomic Managers (called Decision Elements (DEs)) that run as software in the GANA Knowledge Plane and drive self-* operations such as self-adaptation, self-optimization objectives for the network and services by adaptively programmatically (re)-configuring Managed Entities (MEs) in the network infrastructure through various means possible: e.g. through the NorthBound Interfaces available at the OSS(Operations Support System), Service Orchestrator, Domain Orchestrator, SDN controller, EMS/NMS, NFV Orchestrator, etc. The various management and control systems, such as OSS/BSS (Business Support System), E2E Service Orchestrator, and SDN controller, NFV Orchestrator, should be viewed collectively as data/info sources or events sources by the GANA Knowledge Plane. This is because the GANA KP is supposed to be the center of consolidated knowledge about the network and intelligence for autonomic and cognitive management and control of the network infrastructure based on data and knowledge and events obtained from the various systems by the GANA Knowledge Plane. Also because Complex Event Processing (CEP) over events from the various systems is to be performed by the GANA Knowledge Plane as discussed in ETSI White Paper No.16 [1] and GANA Technical Specification [2]. And in turn, the GANA Knowledge Plane DEs may dynamically and selectively fire

commands (thanks to the cognitive and analytics algorithms employed by the KP DEs) into any or some of the systems. This depends on the target systems the GANA KP DEs determine should be used by the DEs' attempt to adaptively and intelligently instantiate, scale-in, scale-out or program the PNFs (Physical Network Functions) and VNFs (Virtual Network Functions) of the underlying network infrastructure. For example, the GANA Knowledge Plane can fire commands into the E2E Service Orchestrator in attempts to achieve analytics-driven orchestration, as may be determined by the Decision Elements (DEs) of the Knowledge Plane. Another possibility is that the KP could fire commands through the OSS (if an OSS is available and is a strategic target for use in (re)-configuring the network), or through the SDN Controller, etc., instead, or in combination to firing commands into the E2E Service Orchestrator. As such, the GANA Knowledge Plane is to be viewed as the "brain" for which implementers should design and implement advanced Autonomic/Cognitive Management & Control (AMC) DE Algorithms that can program network infrastructure via any of the systems available for that and according to the capabilities available on the systems' northbound interfaces. The GANA Knowledge Plane can be viewed as an Advanced Analytics Platform that also retrieves Health Scores Data, Monitoring/Telemetry Data, Topology and Configuration Data from the SDN Controllers for the Production Network and from NEs, and use the data in making the complex decisions in the Closed-Loop (Autonomic) Management and Control operations on the network infrastructure. Other inputs to the Knowledge Plane, required for its autonomic operations (e.g. autonomic service assurance) include Service Definitions and any mappings to QoS (Quality of Service) Classes, SLA Definitions & Customer Identifiers Info/Data from the Service Fulfilment functions (e.g. OSS/BSS).

NOTE: As illustrated later on **Figure 5 and Figure 19**, a GANA Knowledge Plane can be designed and implemented for a specific network segment(domain), rather than having a single large GANA Knowledge Plane that covers multiple segments—as this may follow various incentives (based on technical or administrative or even business models reasons). And so in interactions with other management and control systems such as OSS, Orchestrators and SDN controllers, a GANA Knowledge Plane for a specific network segment programs state into the underlying network infrastructure under its responsibility, and participates in federated operations (dynamic end-to-end network state programming) in collaboration with Knowledge Planes for other network segments/domains.

6. Overall ONAP to GANA Mappings and How ONAP can be used to implement GANA Knowledge Plane Components, and Advancing ONAP accordingly

6.1. The roles of the ONAP Design Time Framework and the Execution Time Framework in Designing and Implementing a GANA Knowledge Plane and its operations

The way to use ONAP in implementing the ETSI GANA Knowledge Plane components can be guided by the approach described in this section and sub-sequent sections that follow, based on the understanding on how the GANA Knowledge Plane can be integrated with SDN controllers, NFV MANO, E2E Orchestration, Big-Data driven analytics for AMC, OSS/BSS and other management and control systems. The GANA Knowledge Plane defines various types of modular autonomic manager components that can be implemented and executed as special management and control services within an ONAP platform(s) deployment, e.g. the *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 same applies with the other GANA Knowledge Plane Functional Blocks (FBs) such as the MBTS and the ONIX system, though the MBTS is supposed to be implemented as a software library as described in ETSI TS 103 195-2 [2]. The GANA Knowledge Plane should be viewed as an integral part of the ***Orchestration and control framework in ONAP*** and can be designed using the ***Design Time Framework* of ONAP** together with other Tools that may not be available in ONAP. KP DEs should consume various service specific events and through their autonomics algorithms apply various strategies for network programming and adaptation that are of relevance to the various KP DEs accordingly. KP DEs can be implemented as part of the ***analytic framework in ONAP*** or that the analytic framework interfaces with KP DEs in order to feed the KP DE algorithms with results of analytics that the KP DEs then consider in their decision-making process for autonomic service assurance, and in DE operations that may also result in analytics-driven (re)-

orchestration of some services by the KP DEs (via commanding appropriate management and control systems) to meet certain objectives (e.g. to guarantee SLAs (Service Level Agreements)).

While it is possible to develop "service operations-specific" collection, analytics, and policies (including recipes for corrective/remedial action) using the ONAP Design Framework [9], implementers of the GANA Knowledge Plane for a specific network segment (e.g. *RAN (Radio Access Network), Fixed Access, X-Haul (e.g. Fronthaul and Backhaul), Edge/MEC (Multi-Access Edge Computing), Data Center (DC), IP Backbone, or Core Network*) should consider that KP DEs are expected to be implemented in such a way as to be able to generate some policies dynamically through their cognitive capabilities for management and control intelligence. Such policies dynamically generated by KP DEs in their dynamic network services policing operations are expected to augment human specified policies (specified using the Policy Creation Framework in ONAP) supplied to the KP as a means to govern the KP's autonomic operations targets. The other aspect implementers of KP DEs should bear in mind is that KP DEs are expected to perform policy control of any DEs implemented in Network Elements/Functions (NEs/NFs) based on the GANA model principles on hierarchical autonomic policy control and Policy Continuum.

The KP DEs should be designed and implemented in such a way as to be able to execute (invoke) or dynamically tune the execution of the **ONAP Common Services** (which manage more complex and optimized topologies). The **MUSIC (Multi-Site State Coordination) service in ONAP** may have a relationship to a single Global Knowledge Plane (KP) or to site specific Knowledge Plane deployments that can be coordinated by a more Global Umbrella Knowledge Plane (KP). In relation to the **ONAP Optimization Framework (OOF)** that provides a declarative, policy-driven approach for creating and running optimization applications like Homing/Placement, and Change Management Scheduling Optimization, the KP DEs should be designed and implemented in such a way as to be able to execute(invoke) or tune the execution of such optimization applications. Such optimization applications could be used to implement part of the logic of a DE(s) depending on DE-to-ME mappings prescribed in ETSI TS 103 195-2 [2]. However, there has to be a mapping that has to be created on answering the question on "which DE(s) influences the execution of a particular ONAP common service or OOF application?", else the ***AutoConfiguration_&_AutoDiscovery-DE of the Knowledge Plane*** can be assigned to perform the invocation or tuning of such ONAP services and OOF applications on behalf of the whole KP's DEs, as it is the one that is expected to perform the overall coordination of all KP DEs.

Regarding the **ONAP Operations Manager (OOM)**, GANA Knowledge Plane DEs lifecycle operations chould also be managed by the OOM.

The following figure (**Figure 5)** illustrates how to position a GANA Knowledge Plane in ONAP and management and control systems in general that can be integrated with the GANA Knowledge Plane Platform as an Overarching Umbrella Analytics Platform that consumes events from the various systems and other types of data sources and can ***autonomically program*** the network and services using the northbound interfaces of the various systems selectively. A GANA Knowledge Plane (KP) may be implemented in various ways that differ in terms of the KP DEs algorithms and intelligence as well as the diversity of data sources (including event sources) that the KP implementers consider as the required data sources that should feed data and events to the KP DEs, and also in terms of the programmatic management and control systems or components through which the KP DEs can program the network resources, parameters and services through the northbound interfaces of those programmatic systems. Therefore, a GANA Knowledge Plane implementation, in contrast to another GANA Knowledge Plane implementation (possibly by a different Knowledge Plane (KP) platform vendor), may have a wider scope/diversity of data sources, events visibility and consumption into its DE algorithms and decision-making processes, as well as the variety(diversity) of management and control systems through which the KP DEs can be designed to execute autonomic operations that (re)-program the resources, parameters and services of the underlying network infrastructure(s) via the northbound interfaces exposed by such systems.

Therefore, as illustrated on Figure 5, various management and control systems in general can be integrated with the GANA Knowledge Plane Platform as an Overarching Umbrella Analytics Platform that can consume events from the various systems and other types of data sources and can autonomically program the network and services using the northbound interfaces of the various systems selectively.

NOTE: [17] discusses the subject of "Knowledge Plane-Driven" Orchestration—based on Business Goal Incentives or Autonomic Remediation Strategies Execution by the KP; and Selective Multi-Layer Programming Targets by KP Autonomics

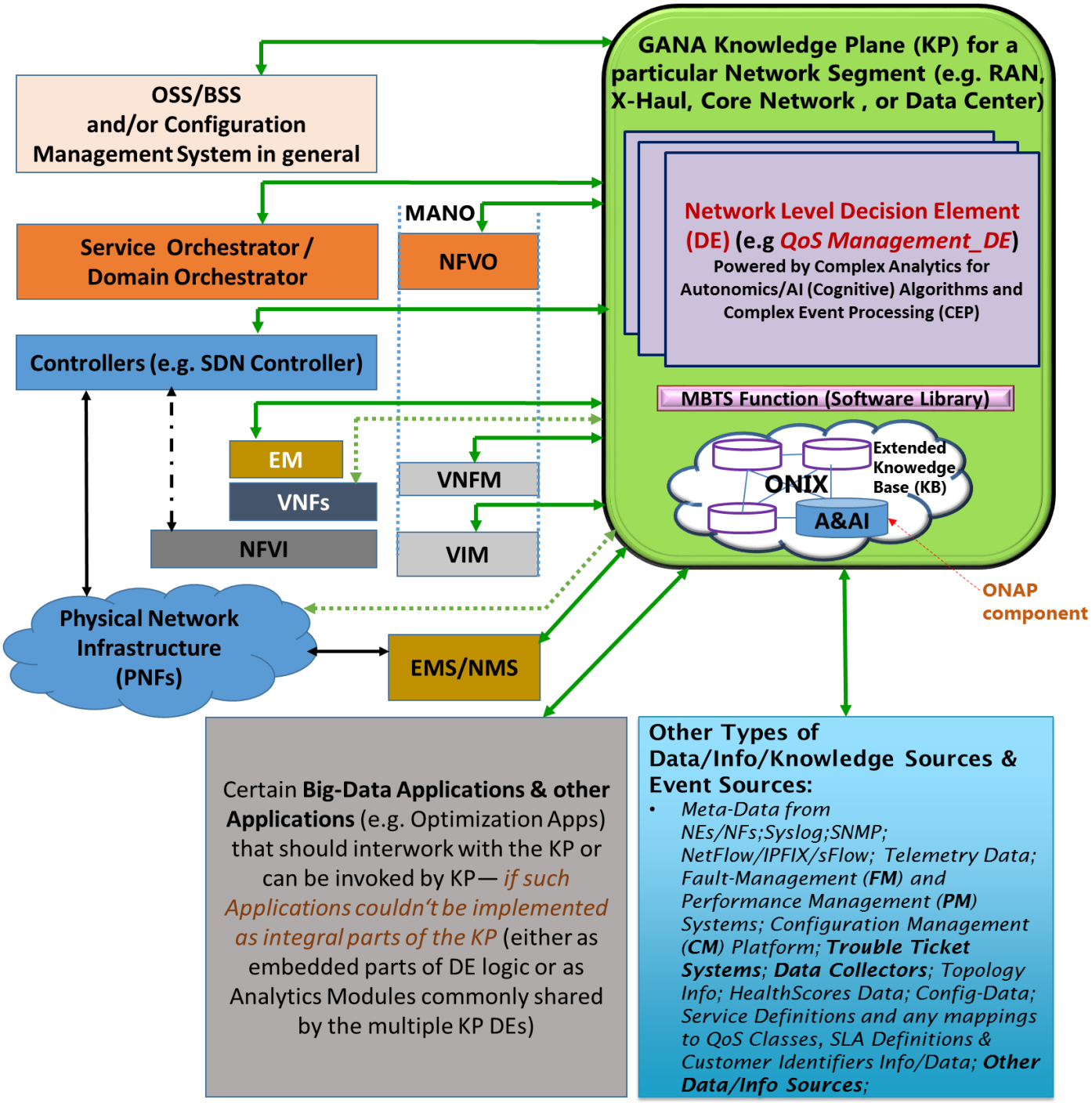

Figure 5: ***The Integration of the GANA Knowledge Plane with various management and control systems through which the Knowledge Plane can selectively program the network; and Event Sources, Data Sources and Info/Knowledge Sources***

NOTE-1: As discussed in the ETSI TS 103 195-2 [2], Knowledge Planes may be designed to integrate with some traditional OSS systems while in some deployments of a Knowledge Plane the Knowledge Plane can take over the role of an OSS. Also, in some deployments of network management and control systems there may be some co-existence of a traditional OSS and some Configuration Management System(s) of some sort being used complementarily, while in some cases (e.g. in enterprise

networks) only a Configuration Management System(Platform) may be in use. Later in this paper, the elements of ONAP that can be used to implement a GANA Knowledge Plane are elaborated in more detail.

NOTE-2: Regarding the MBTS Function, there are various options that could be considered and possibly one or more options may be complementarily implemented:

1. The MBTS Function (as a Software Library as described in ETSI TS 103 195-2 [2]) can be implemented and integrated with the KP DEs.
2. The MBTS Function can be implemented as SouthBound Interface of an SDN Controller as described in sources indicated in the ETSI White Paper No.16[1].
3. The MBTS Function can be implemented as integral part of Configuration Management System Platform, OSS, or Network or Element Management Component of some kind. However, ETSI TS 103 195-2 [2] provides some guidance and insights on how the MBTS function can be implemented.

Later in this paper, the elements of ONAP that already implement some aspects of a MBTS function are described.

NOTE-2: Regarding the ONIX system of federated information servers that collectively federate to support a unified interface for "***Publish/Subscribe/Query&Find(Discover)***" *services* to some entities (subject to security and access control policies), ETSI TS 103 195-2 [2] provides some insights on how ONIX could be implemented. Later in this paper, the elements of ONAP that can be used to implement or integrate ONAP with ONIX concept are described.

Figure 6 (based on an extract from ONAP White Paper [9]) illustrates how to use ONAP Design Time Framework to design GANA Knowledge Plane components and the Execution Framework to implement/deploy components for the GANA Knowledge Plane and extend ONAP accordingly

Using the ONAP Design-Time Framework to design and implement a GANA Knowledge Plane:

- While the ONAP Design-Time Framework can be used to design and implement a GANA Knowledge Plane (KP), it has to be noted that additional development tools such as Modeling tools, and Simulators, Validators, Code-Generators, and other kinds of development tools that may not be available in ONAP may be complementarily required in KP DEs design and implementation.
- KP DEs Coordination Primitives and methods should also be considered when designing DEs and their interactions (using guidance by the ETSI TS 103 195-2 [2]).
- While the Design-Time Framework enables to create workflows, policies and methods to implement Closed Loop Automation/Control and manage elastic scalability [9], a Knowledge Plane needs to be able to exercise some of the closed-loop operations while the user could simply then define the inputs that should be used to govern the KP's operations and then configure the KP DEs accordingly to operate in closed-loop mode.
- While the ONAP Policy Creation component deals with polices (rules, conditions, requirements, constraints, attributes, or needs that must be provided, maintained, and/or enforced) [9], certain of such policies should provide for the inputs that can be supplied to KP DEs as a way to govern the KP DEs autonomic operations at run-time
- While the Closed Loop Automation Management Platform (CLAMP) provides a platform for designing and managing control loops, and CLAMP is used to design a closed loop, configure it with specific parameters for a particular network service, then deploy and decommission it [9], implementers of KP DEs should bear in mind that multiple KP DEs are required to collaborate for the autonomic management and control of the various network services created in this way in ONAP. While there is the possibility that once deployed, a user can also update the loop with new parameters during runtime, as well as suspend and restart it, autonomics by the KP DEs should be envisaged to enable the user to interact with the user in this fashion.

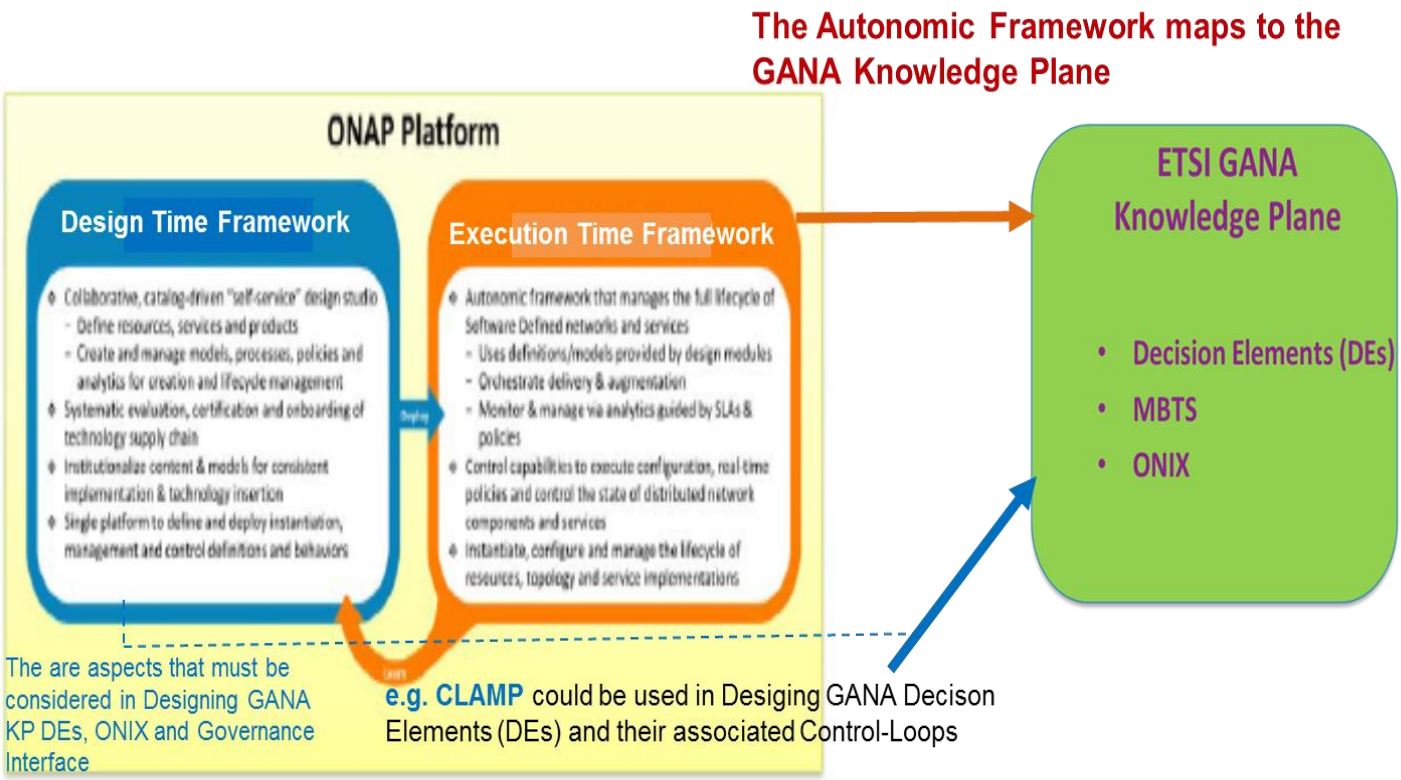

Figure 6: ***Using ONAP Design Time Framework to design GANA Knowledge Plane components and the Execution Framework to implement/deploy components for the GANA Knowledge Plane and extend ONAP accordingly***

Points to take note of on using the ONAP Run-Time Framework to design and implement a GANA Knowledge Plane:

- The **Active and Available Inventory (A&AI)** can be used in such a way that it could be a member of the GANA ONIX system, federating with other Information Servers of the GANA ONIX system that network operator or an enterprise gets to deploy to facilitate for advanced auto-discovery of resources/information by various consumer entities that may need such information
- The Knowledge Plane should interface with the ONAP MUSIC component to autonomically manage state across sites, in an E2E closed loop fashion.
- While the **ONAP External API** provides access for third-party frameworks such as MEF, TM Forum and potentially others, to facilitate interactions between operator BSS and relevant ONAP components [9], the Knowledge Plane (KP) may also likewise be implemented to integrate through that API.
- Regarding the **Orchestration part in ONAP**, the KP should also make use of the External API Northbound Interface part that provides a standards-based interface between the BSS and various ONAP components, including Service Orchestrator, A&AI and SDC [9], in its analytics driven orchestration of services and the autonomic operations that a KP can exercise in interaction with an Orchestrator as described earlier in this document.
- The KP needs to be aware of any newly instantiated network service in order to perform autonomic service assurance of the service continuously throughout the lifecycle of the service.
- A Knowledge Plane can be implemented or configured to operate in a mode that is complemented by other management and control systems that could be used to perform service instantiation and initial configuration while the KP is then left to perform the self-* operations (such as *self-optimization, self-diagnosis and self-healing operations, etc.*) for the closed-loop (autonomic) Service Assurance that brings about the notion of self-managed networks and services.

- Regarding **Policy-Driven Workload Optimization part of ONAP**, the KP DEs may employ services such as Optimization Applications or Services created using the ONAP Optimization Framework (OOF), e.g. OOF Homing and Allocation Service (HAS)[9], in their autonomic management and control intelligence objectives and operations. A KP is supposed to be designed and implemented to perform State Correlation across multiple factors. In the broader picture, KP DEs should be implemented in such a way as to achieve Autonomic Service Assurance to fulfil performance and security SLAs (Service Level Agreements) among the various targets of KP DEs. **NOTE:** An Optimization application(s) could be used to implement part of the logic of a DE(s) depending on DE-to-ME mappings prescribed in ETSI TS 103 195-2 [2].
- Regarding **Controllers in ONAP**, as illustrated in **Figure 5**, the KP should interface with controllers as they serve as event sources and the KP DEs can use them to program the network via their northbound interfaces as driven by the cognitive management and control algorithms of KP DEs
- KP DEs should store a trace (log) of their Decisions computed (with mappings to contexts/situations) and executed over time, in ONIX, and so KP DEs could possibly store such historical information (with mappings to contexts/situations) in the Active and Available Inventory (A&AI).

Figure 7 (based on an extract from ONAP White Paper [9]), indicates the need for GANA Concepts to be used to extend the Information Models in ONAP, and this can be done by leveraging the idea of creating a GANA Meta-Model Specification as discussed in ETSI TS 103 195-2 and later in section 6.3.

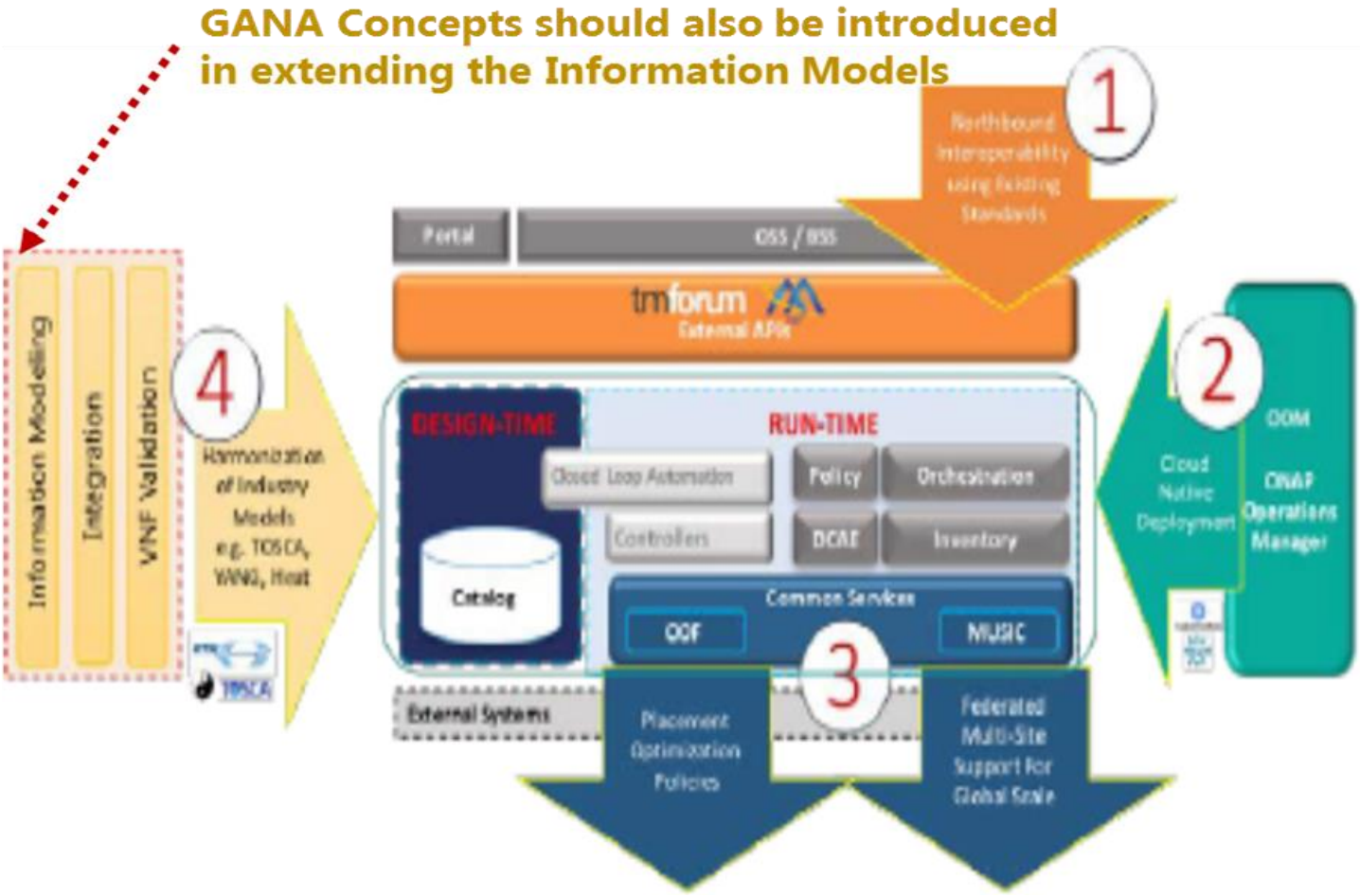

Figure 7: ***GANA Concepts should also be used to extend the Information Models in ONAP***

6.2. ONAP Closed-Loop Automation Aspects that should be applied to Implement the ETSI GANA Knowledge Plane (KP) Components (e.g. DEs, ONIX and KP Governance Interface)

The figure below (**Figure 8**), based on an extract from ONAP White Paper [9], considers *Automated Service Lifecycle* aspects that belong to design aspects versus the aspects that belong to execution time consideration, and illustrates the ONAP Closed-Loop Automation aspects that should be applied to implement the ETSI GANA Knowledge Plane (KP) Components (e.g. DEs, ONIX and KP Governance Interface).

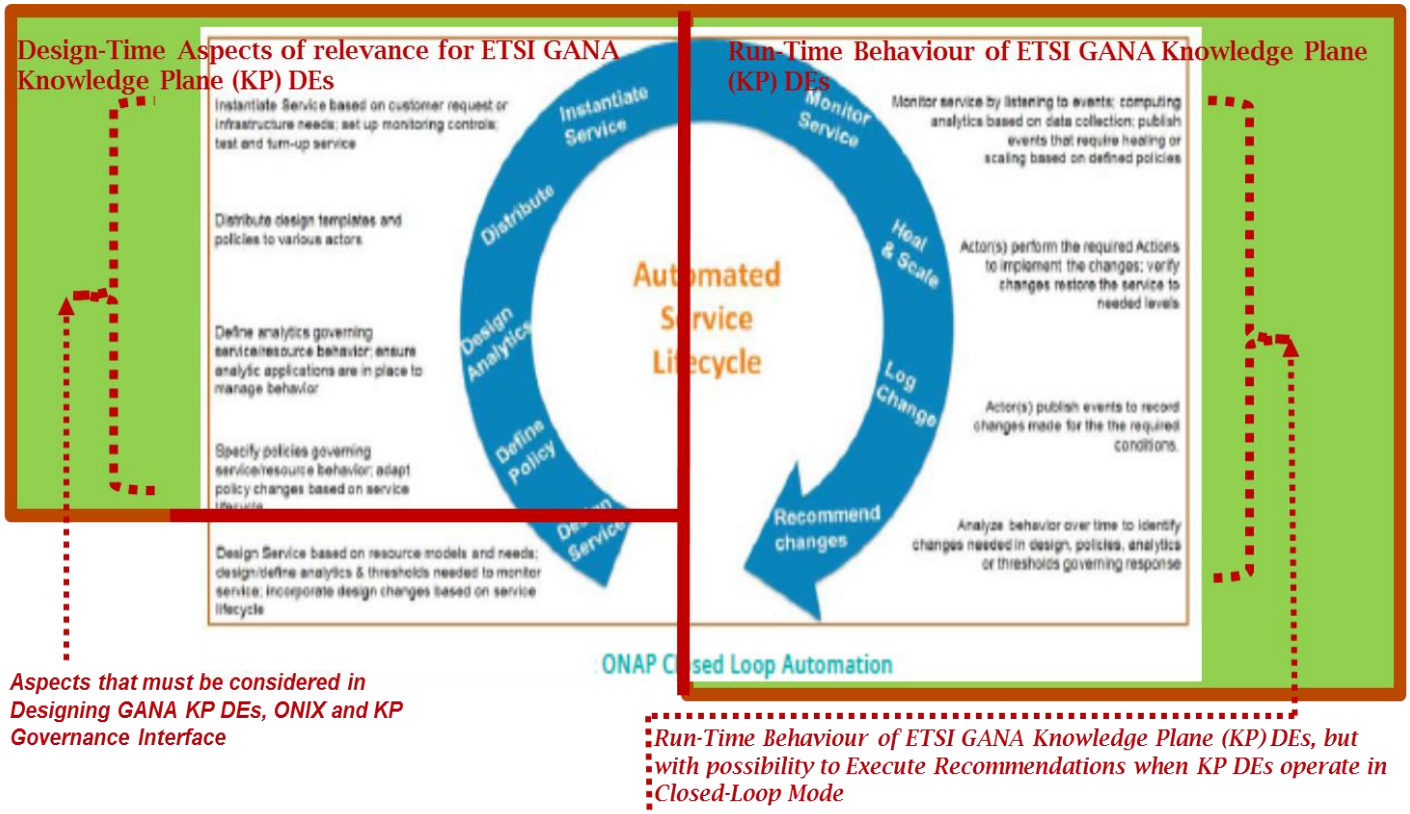

Figure 8: ***Design-Time Aspects of relevance for ETSI GANA Knowledge Plane (KP) DEs, and Run-Time Behaviour of ETSI GANA Knowledge Plane (KP) DEs***

According to ETSI TS 103 195-2, Closed-Loops of DEs should be governed by use of what is called a GANA Profile (used to provide goals and other inputs for control and operation of a control loop). A Closed Loop should be defined and implemented per KP DE. KP DEs should run as specialized autonomic management and control services, and a number of DEs are defined in the GANA specification (ETSI TS 103 195-2), i.e. DEs such as *AutoConfiguration_&_AutoDiscovery-DE, QoS Management-DE, Monitoring Management-DE, Routing Management-DE, Forwarding Management-DE, Resilience & Survivability Management-DE, Fault Management-DE, Mobility Management-DE*.

6.3. CLAMP orchestration on different levels and considerations of the levels in GANA KP Implementation

CLAMP orchestration on different levels (see **Figure 9** below that is based on an extract from ONAP White Paper [9]) imply that Knowledge Plane DEs can be designed and implemented to drive analytics-driven orchestration at the various levels, by which KP DEs selectively employ(use) orchestrators and controllers to dynamically program network infrastructure according to the management and control intelligence (e.g. ***autonomic self-healing, self-repair, self-optimization) targets(objectives) of the Knowledge Plane***.

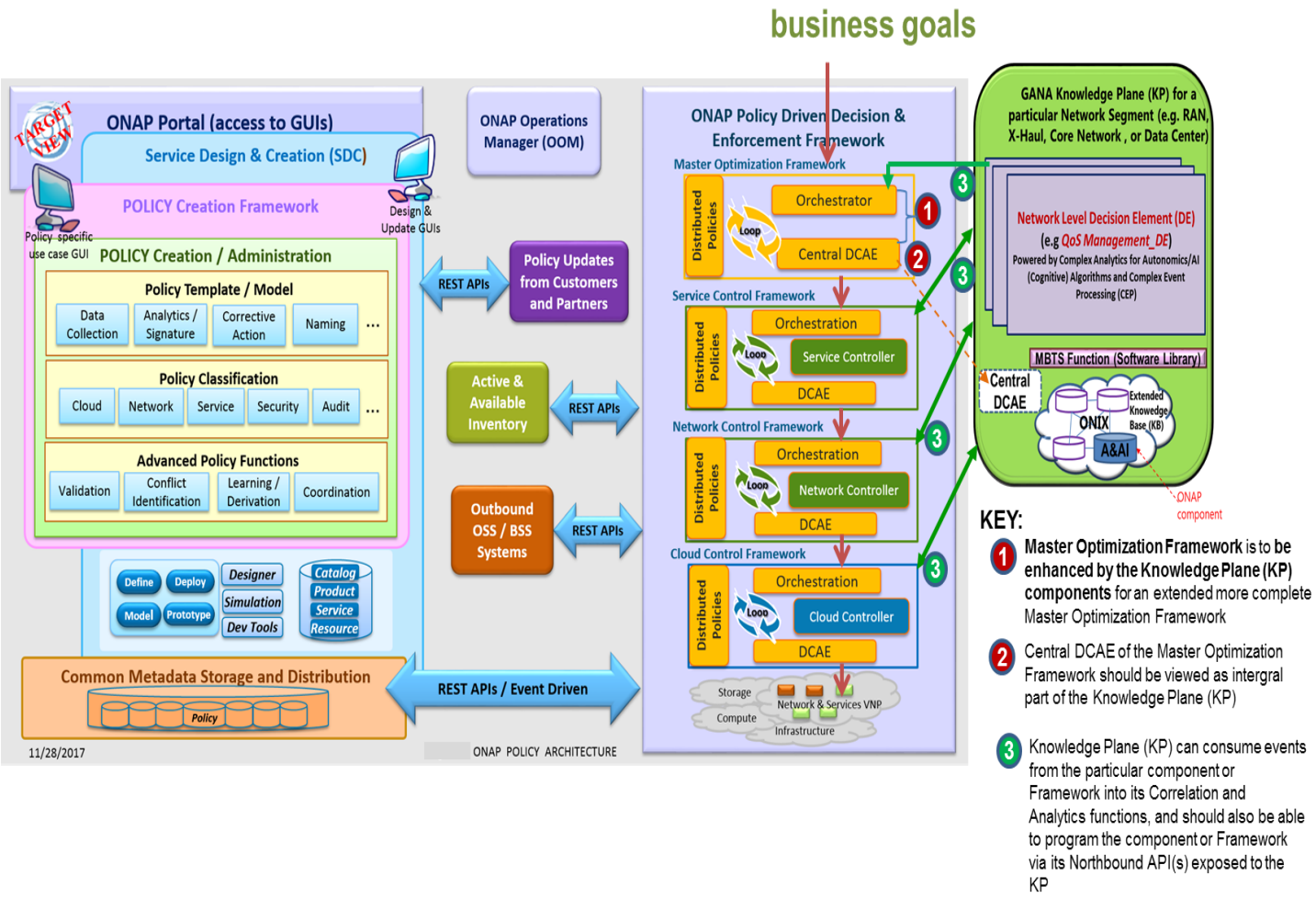

Figure 9: ***ONAP Policy Architecture and CLAMP orchestration on different levels that can be dynamically driven by Knowledge Plane DEs to achieve analytics-driven orchestration and Autonomic Service Assurance***

Implementers of the GANA Knowledge Plane (KP) should consider the Vertical and Horizontal Reference Points (Rfps) defined and described in ETSI TS 103 195-2 concerning KP Reference Points on the boundaries of a GANA Knowledge Plane and also Reference Points internal to the KP, according to the target environment for which the GANA Knowledge Plane is to be implemented/deployed to run. As such the consideration of the KP Reference Points means taking into account the Characteristic Information associated with a particular Reference Point (Rfp) as described ETSI TS 103 195-2 [2] and providing the means (API or protocols) to implement the Reference Point and exchange of Characteristic Information (with possibility to elaborate and extend the characteristic information according to the target environment for which the GANA Knowledge Plane is to be implemented/deployed to run). Examples of such KP Rfps described in ETSI TS 103 195-2 [2] are:

- KP Governance Rfp (e.g. *OSS/BSS-to-Network-Level-DE through G-MBTS*)
- Inter KP DEs coordination Reference Point (*NetworkLevelDE-to-NetworkLevelDE Reference Point*)
- ONIX associated Reference Points

- MBTS associated Reference Points
- AMC Federation Reference Points

Other aspects that implementers of a GANA Knowledge Plane should consider are:

- Aspects such as the DE Model and Interfaces and the primitives that should be supported on DE interfaces as described in ETSI TS 103 195-2
- Requirements described in ETSI TS 103 195-2 concerning *Requirements for APIs Necessitated by the Unified Architecture for ETSI GANA Knowledge Plane, SDN NFV, E2E Orchestration, Big-Data driven analytics for AMC*
- Aspects described in the Further Work part of the ETSI TS 103 195-2, such as the following aspects, should also be considered:
    - A Framework for DE-to-DE Coordination for Conflict Avoidance and Stability in Management and Control Operations: the required primitives and data model, etc., based on the relevant insights on the subject of synchronization and coordination of DEs (autonomic managers) described in ETSI White Paper No. 16, ETSI TS 103 195-2 [2], and in other sources in literature.
    - Policy Control Frameworks that can be applied in GANA, within NE/NF's internal DEs and control-loops, and in the outer loop driven by Knowledge Plane DEs, with consideration of Policy Continuum.
    - The Formal Description of the GANA Reference Model in form of a GANA Meta-Model that describes the GANA concepts, relationships and constraints using a modelling language such as UML (Universal Modeling Language by OMG organization), MOF (Meta-Object Facility by OMG organization), or other modelling languages. Such work on a GANA Meta-Model had been started as discussed in ETSI TS 103 195-2 using the GME modelling environment, and could be used as starting basis to complete the work on a GANA Meta-Model development.
    - Methods for Knowledge Representation and Presentation to Knowledge Plane DEs.

NOTE: More details are provided later on APIs Requirements in the context of ONAP for GANA Knowledge Planes Implementations (APIs between KP DEs and DCAE, KP DEs and ONAP Applications, etc.)

6.4. Overall Identification of the ONAP Components that can be used or extended to Implement GANA KP Components

The following figure (**Figure 10 —** based on an extract from ONAP White Paper [9]) provides an indication of the overall identification of the ONAP Components that can be used or extended to implement GANA KP Components. As shown on the figure 10, the GANA KP needs to interface and interact with the ONAP Policy Management Framework (i.e. Policy Execution Engine) components such as PAP (Policy Administration Point), PDP-X (Policy Decision Point-X) and PDP-D (Policy Decision Point-D) for the purposes described in more details later in section 6.6.

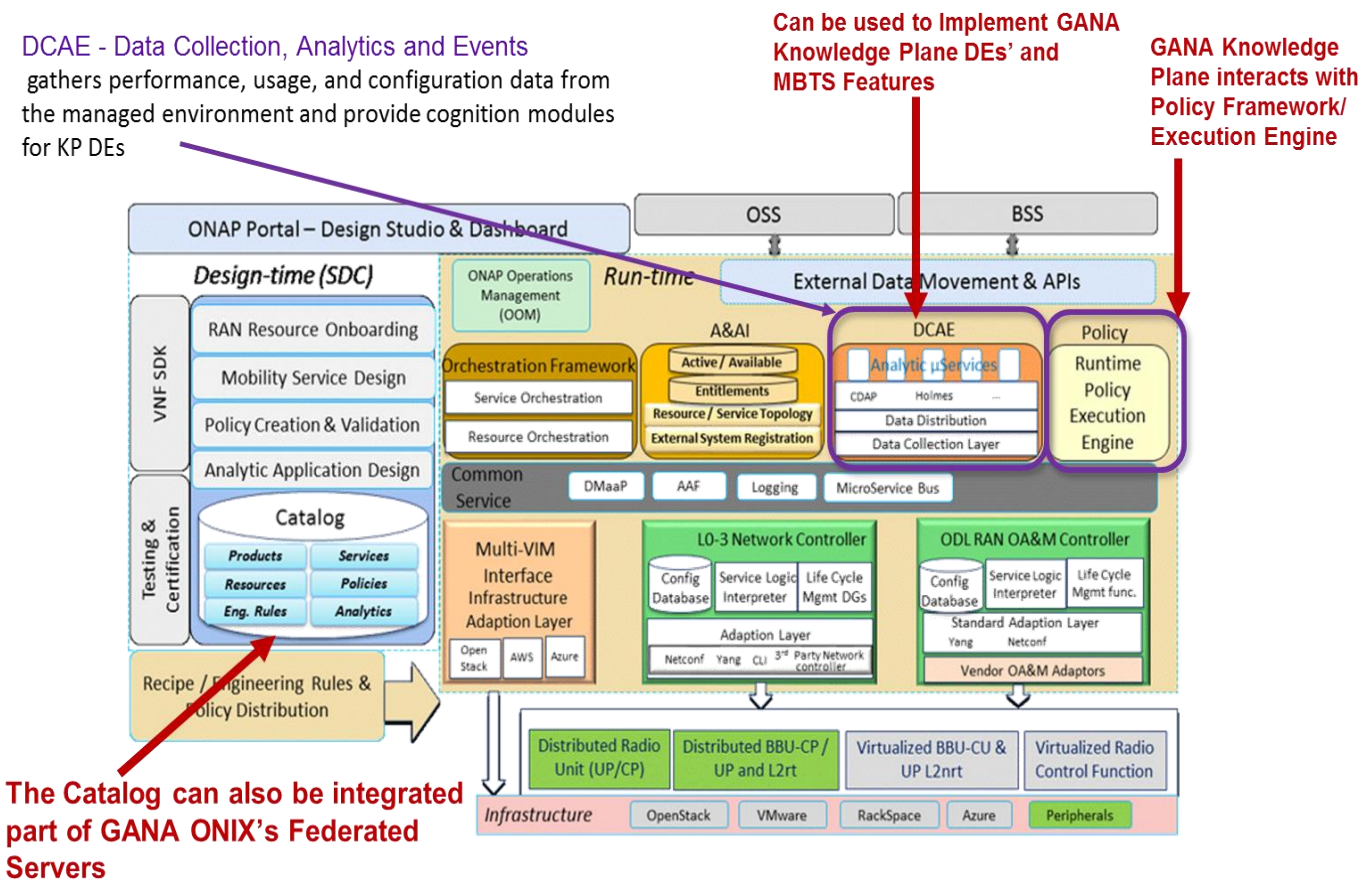

Figure 10: ***Overall Identification of the ONAP Components that can be used or extended to Implement GANA KP Components***

The Cognition Module of DE Logic is supposed to be powered by analytics application(s) that can be implemented either as integral part of a DE or can be invoked by a DE or can be interfaced with the DE to feed its decision-making algorithms with results of analytics. This means a Cognition Module employed by a DE can be embedded or is external to the DE such that the cognition module can be commonly shared by multiple DEs. A DE has an internal Policy Server/Repository part that can generate dynamic policies during the DE's operation and also takes as input any policies for the DE provided by a human operator through some management tools to govern the DE's operations.

6.5. ONAP DCAE Analytic Applications and DCAE Platform collectively help implement the GANA Knowledge Plane (KP)

6.5.1 Overview

ONAP DCAE Analytic Applications and DCAE Platform collectively help implement the GANA Knowledge Plane as illustrated on **Figure 11** (based on an extract from ONAP [9]).

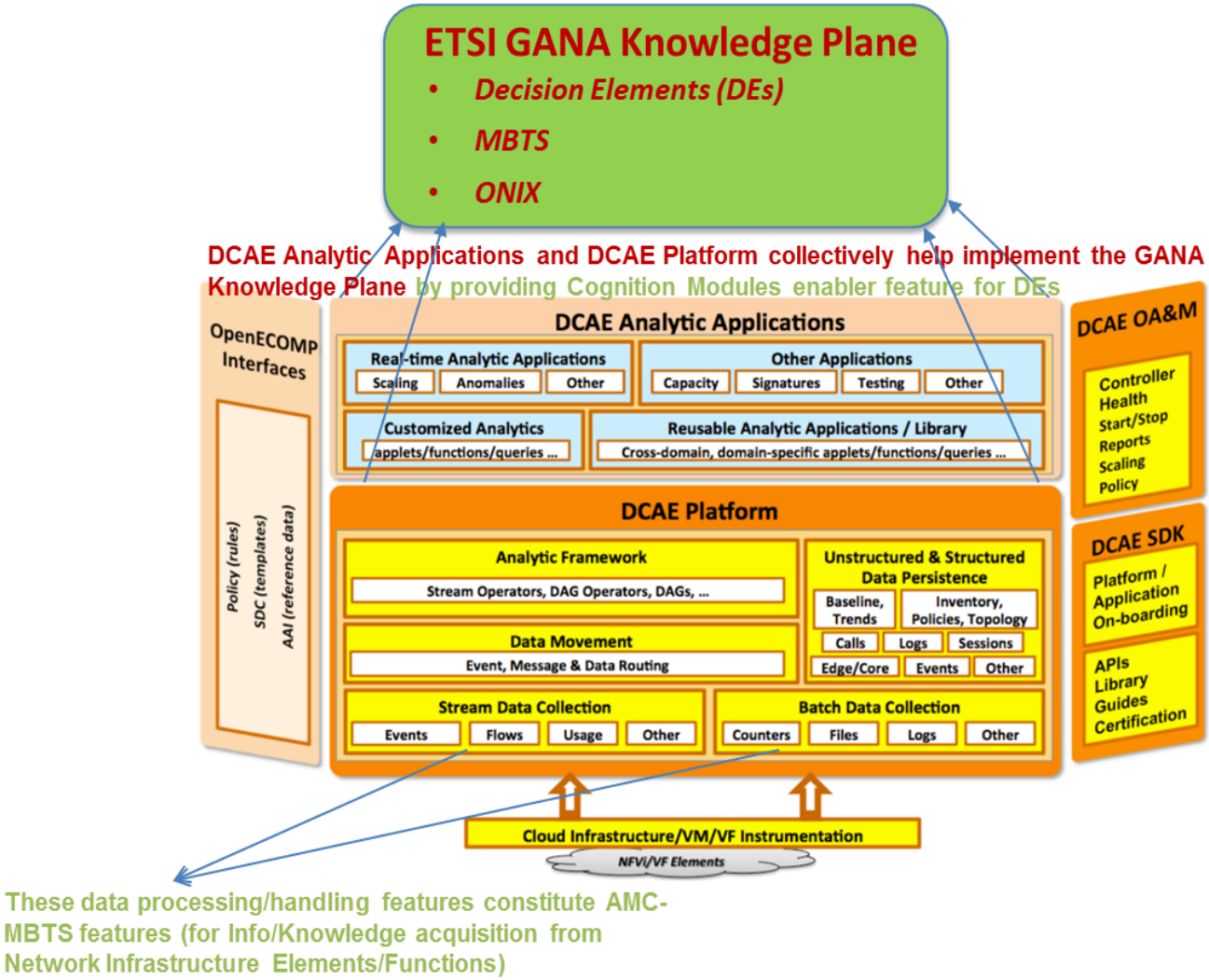

Figure 11: ***DCAE Analytic Applications and DCAE Platform collectively help implement the GANA Knowledge Plane; and data processing/handling features constitute AMC-MBTS features (for Info/Knowledge acquisition from NEs/NFs)***

The following figure (**Figure 12**), based on an extract from ONAP [9], illustrates how Knowledge Plane DEs, ONIX and MBTS components should interact with the ONAP DCAE Platform and DCAE Analytic Applications. **NOTE:** While the figure 12 touches on the subject of relationships between the KP and policies, more details on this subject are found later in section 6.6.

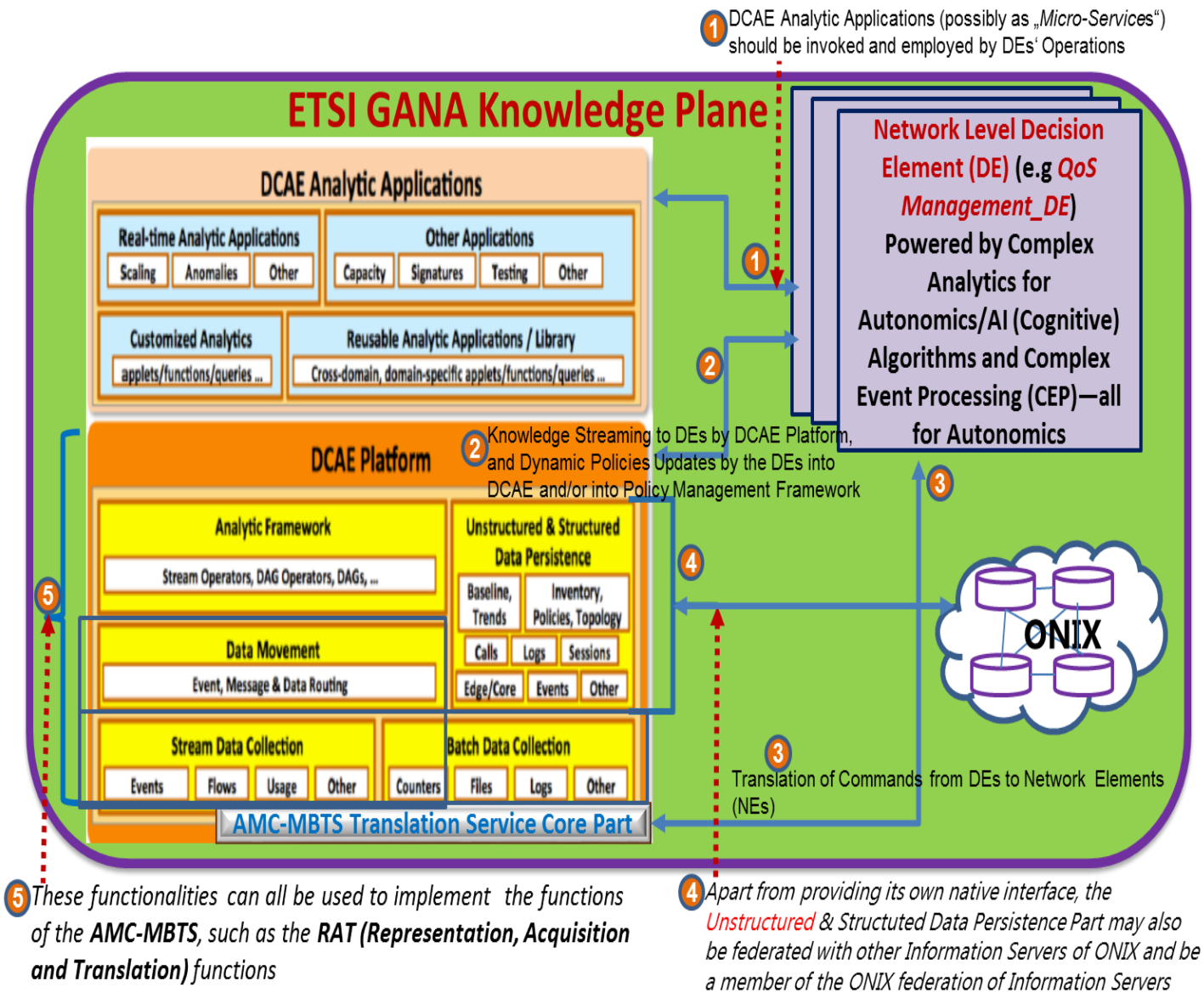

Figure 12: ***How KP DEs, ONIX and AMC-MBTS components should interact with the ONAP DCAE Platform and DCAE Analytic Applications, with AMC-MBTS as the integral part of the implementation of the SouthBound Interface of the DCAE***

6.5.2 Approach-1 on Implementing KP DEs: Analytics Apps and DCAE components serving as commonly shared services or data sources for all the KP DEs

In this approach a KP DE implementer could consider making the ***Network Level AutoConfiguration_&_AutoDiscovery-DE*** orchestrate and dynamically tune the operations of Analytics Apps and DCAE components that serve as commonly shared services or data sources for all KP DEs as illustrated by Figure 13. If any of the Analytics Apps would send commands to the DCAE in attempt to install state in the network infrastructure elements (PNFs or VNFs) then such operations should be controlled by a KP DE that is expected to make decisions on changes to Managed Entities (MEs) that would be targeted by the Analytics Applications, otherwise the Analytics Application in question should have its actions controlled (permitted or denied)

by the KP DEs through the *Network Level AutoConfiguration_&_AutoDiscovery-DE* as the global coordinator of actions from the KP DEs to such Analytics Apps that are designed to effect a change in MEs state via DCAE. Otherwise, ideally, Analytics Apps should be designed to run as services that produce analytics output that can be consumed by multiple KP DEs and not be designed to send any actions to change MEs state as this should be left to KP DEs to consume the analytics output and compute actions and plans that are meant for changing MEs state in the network infrastructure accordingly.

Figures 13-15 (based on an extract from ONAP [9]) also illustrate how GANA KP DEs interface with PDPs in ONAP, interfacing of the KP with NEs, and components that can be used to implement AMC-MBTS component (software library) specified in ETSI TS 103 195-2. While the figures 13-15 touch on the subject of relationships between the KP and policies, more details on this subject are found later in section 6.6.

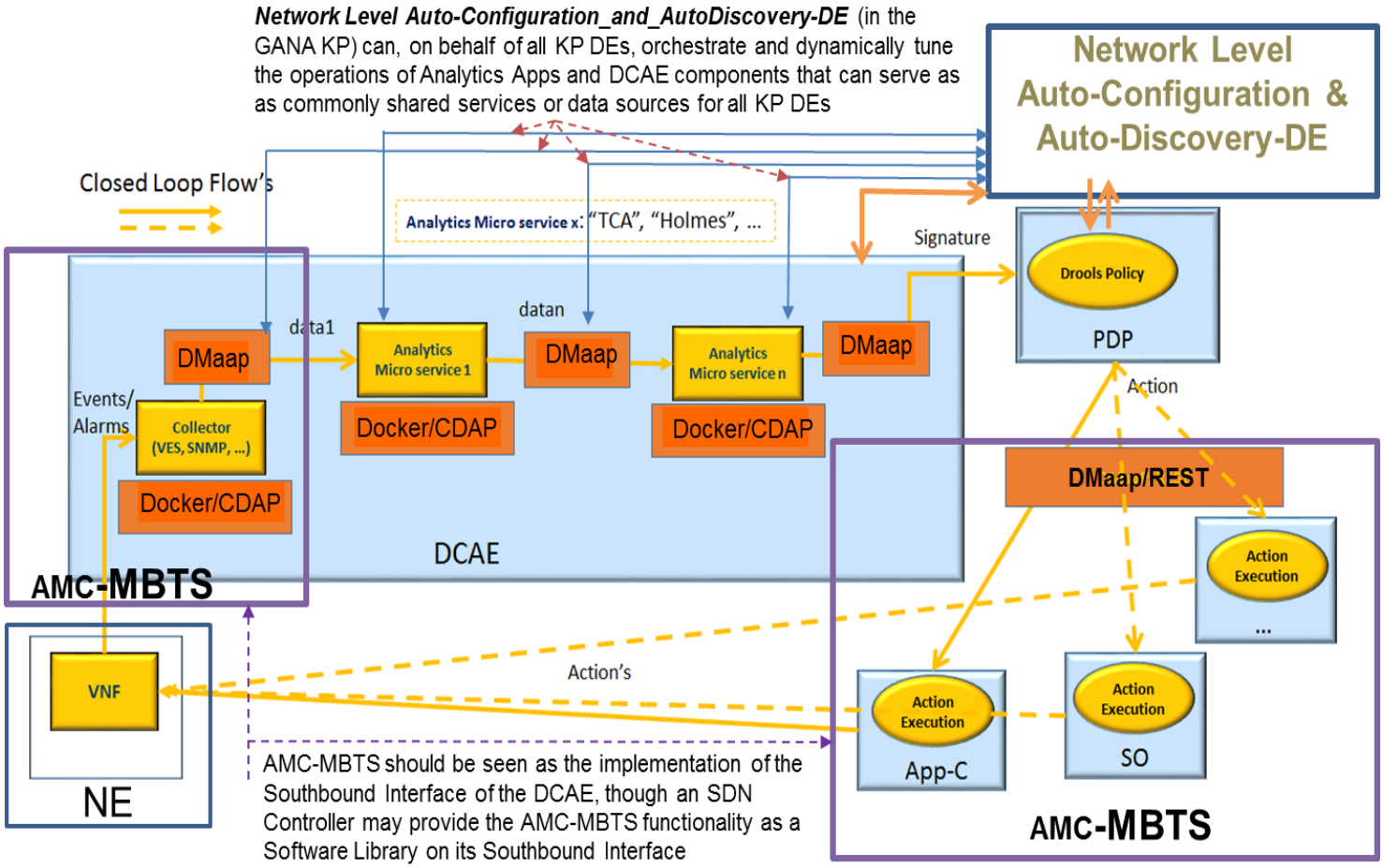

Figure 13: ***Approach-1 on Implementing KP DEs: Analytics Apps and DCAE components serving as commonly shared services or data sources for all the KP DEs: KP AutoConfiguration_&_AutoDiscovery-DE orchestrates and dynamically tune the operations of Analytics Apps and DCAE components on behalf of all KP DEs***

As illustrated in the diagram below (figure 14), as the ***Network Level AutoConfiguration_&_AutoDiscovery-DE*** orchestrates and dynamically tune the operations of Analytics Apps and DCAE components that serve as commonly shared services or data sources for all KP DEs, the other KP DEs focus on consuming Data and Analytics Output from DCAE and Analytics Apps, respectively, and use the inputs in their Decision-making Operations that can result in the consumer DE sending control commands to the Analytics Apps via the Network Level Auto-Configuration_and_AutoDiscovery-DE if the Analytics App is one that could send commands that install state in the network.

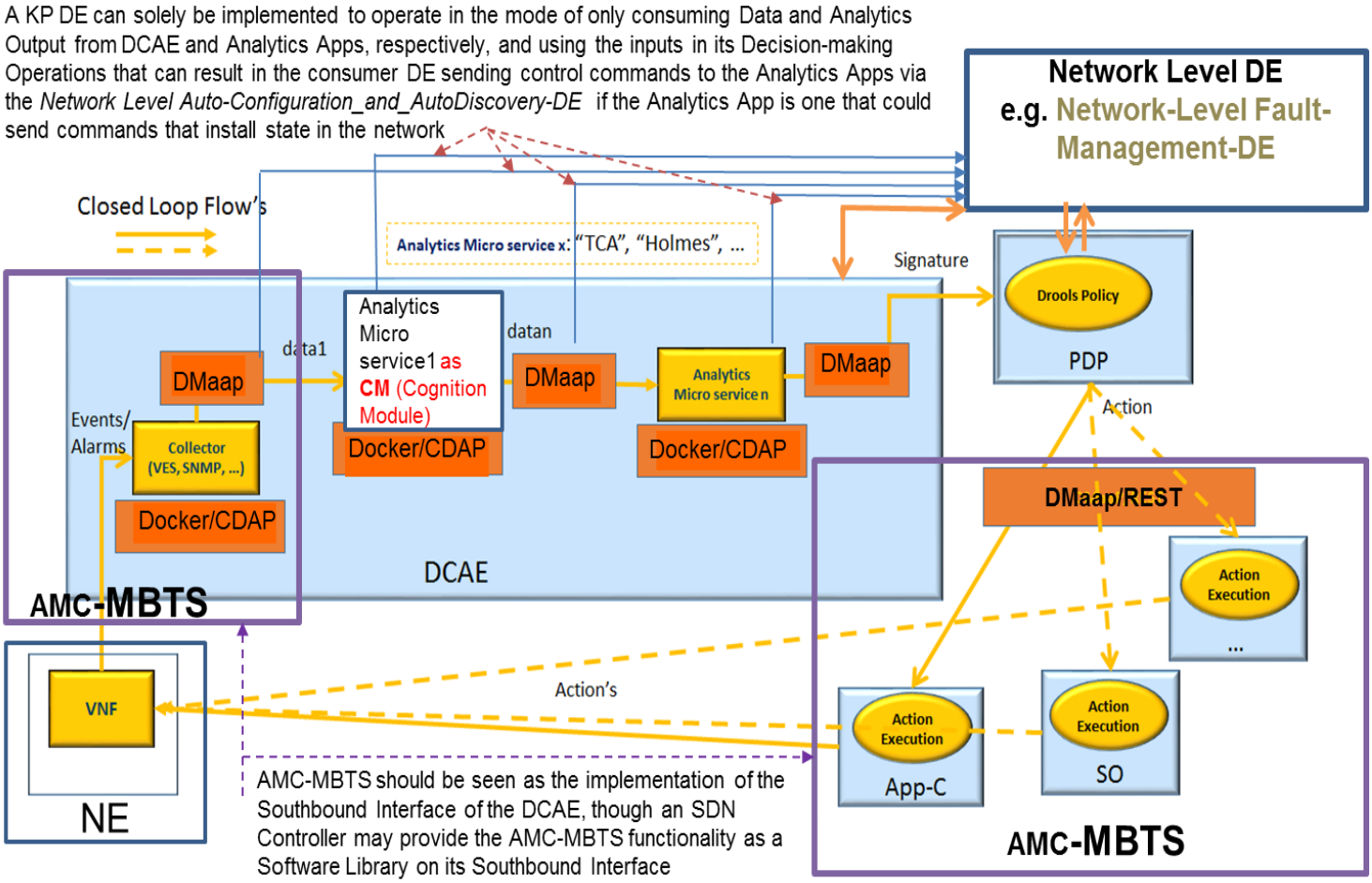

Figure 14: ***Approach-1 on Implementing KP DEs: Analytics Apps and DCAE components serving as commonly shared services or data sources for all the KP DEs: KP DEs operating in a mode of only consuming Data and Analytics Output from DCAE and Analytics Apps***

6.5.3 Approach-2 on Implementing KP DEs: Embedding some Analytics App(s)) and some DCAE components as owned and contained within the scope a particular DE and not being commonly shared among various KP DEs

In this approach (illustrated in Figure 15) a KP DE implementer could consider implementing a KP DE in such a way that some elements (Analytics App(s)) and some DCAE components) are to be considered as owned and contained within the scope of the particular DE and not being commonly shared among various DEs, provided that this approach is viable for some reasons.

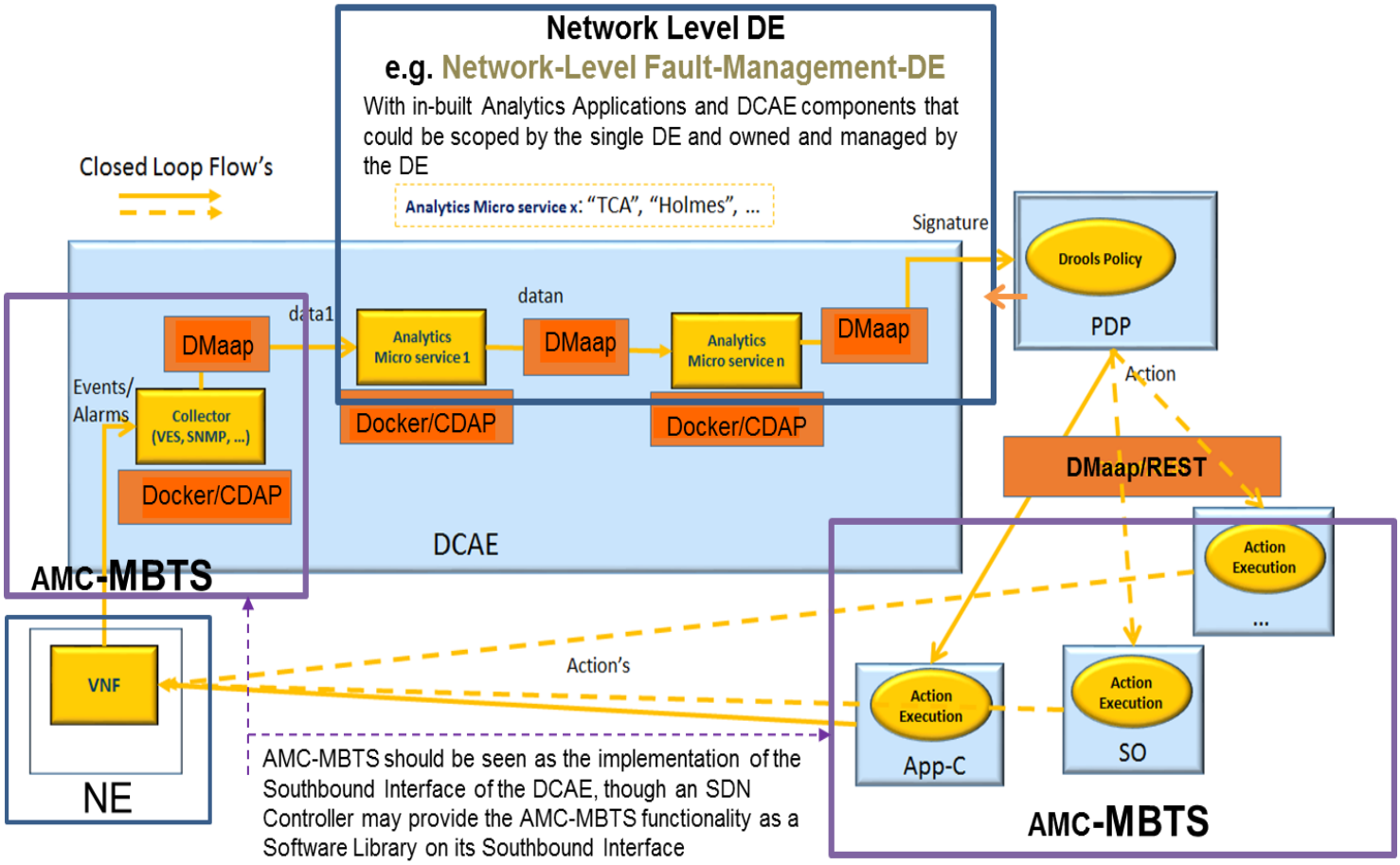

Figure 15: ***Approach-2 on Implementing KP DEs: Embedding some Analytics App(s)) and some DCAE components as owned and contained within the scope a particular DE and not being commonly shared among various KP DEs***

NOTE: For more options on how a KP DE can interface and interact with a PDP in ONAP, and how a PDP concept relates to a DE in general, section 6.6 provides more details. However, in general, a PDP concept (outside of ONAP) should be part of KP DE logic (details on this subject can be found in ETSI TS 103 195-2).

6.6. Options on Integration of the GANA Knowledge Plane (KP) with the ONAP Policy Architecture (Policy Management) Framework

6.6.1 Option-1: ONAP Policy Architecture (Policy Management) Framework interworking with the Knowledge Plane components but being considered external to the Knowledge Plane

Figure 16 below, based on an extract from ONAP [9], illustrates how the GANA Knowledge Plane can be integrated with the ONAP Policy Architecture (Policy Management) Framework as follows:

- **KP Interface with PAP**: The KP DEs need to be able to perform Dynamic Policies Creation or Modification by interacting with the PAP. The types of policies the KP DEs may dynamically create are associated with their cognitive capability to analyze the network state and make self-* operations (e.g. self-optimization of the network, self-protection of the network, etc.) over the network infrastructure to meet new business goals, context changes, or for adaptation of network infrastructure to changing workloads or to various kinds of challenges such as manifestations

of faults/errors/failures/threats and service(s) performance degradations. KP DEs compute and dynamically create new policies and plan the deployment of the adaptation policies using the ONAP Policy Framework such that Policy Enforcement Points (PEPs) receive the policies and enforce the policies. Targets (i.e. PEPs) for dynamic policies by the KP DEs include the various kinds of components through which the KP DE algorithms can program the network (as described earlier, including SDN Controllers, OSS, Orchestrators, NFV MANO, PNFs/VNFs, EM/NM, etc.). The KP DEs can employ the ONAP Policy Framework to distribute the KP generated policies to the specific targets that are policy controlled by the KP DEs.

- **KP Interface with PDP-X:** As described in ETSI TS 103 195-2 [2,] KP DEs need to be governed by Policies and such policies can be defined by the human operator and cleaned of any conflicts before they can be distributed and consumed by the KP through the PDP-X. There are two types of policies that should be provided as inputs to DEs via the PDP-X:
  (1) Policies that govern the "operating region" for each KP DE and are used to configure a DE itself;
  (2) Policies that are meant to govern the network infrastructure elements' (PNFs/VNFs) behaviors and are supposed to be provided as inputs to the KP DEs so that the DEs generate configuration data for the network infrastructure elements (PNFs and VNFs) and their internal DEs and Managed Entities (MEs) from the input policies, i.e. KP DEs can act as "interpreters" of the high level policies defined by the human using the ONAP Policy Design and Policy Conflicts resolution framework. The Conflict-free policies are provided as inputs to the KP DEs and as described in ETSI TS 103 195-2 the KP DEs should package policies and low level configuration data for lower level DEs and Managed Entities (MEs) in PNFs/NVFs using a GANA Network Profile. The ONIX can be used for storing a mapping of policies to network contexts and situations that triggered policy changes by the KP DEs. Such a scenario of involving KP DEs as low level configuration data generators from the input policies is viable for a KP implementation option that is meant to make the KP participate in both the initial and adaptive (re)-configuration of network service meant to be offered by a PNF(s) and VNF(s) of the network infrastructure. **NOTE:** Section 6.10 further elaborates on Implementation Options on the role the Knowledge Plane (KP) can play in Network Service Configuration and Autonomic Service Assurance in ONAP environments. **Remark:** The question of whether the KP should influence in some way the way the PDP-X behaves remains an open question, e.g. possibly the KP could policy the PDP-X as to what policies should not be enforced by certain entities without the approval of the KP (possibly this influence on the PDP-X by the KP could be achieved using "Guard Policies".
- **KP Interface with PDP-D:** The KP needs to interface with the PDP in a bi-directional communication (with involvement of the DMaap) involving Stateful CL Inbound Transactions by KP DEs and KP DEs influencing or controlling PDP-D behaviours, e.g. the KP could policy the PDP-D as to what policies should not be enforced by certain entities without the approval of the KP (possibly this influence on the PDP-D by the KP could be achieved using "Guard Policies". **NOTE:** Section 6.10 further elaborates on Implementation Options on the role the Knowledge Plane (KP) can play in Network Service Configuration and Autonomic Service Assurance in ONAP environments.

NOTE: In other GANA KP implementations approaches outside of ONAP based GANA KP implementation and integrations with ONAP, the concept of a PDP (Policy Decision Point) is a logic that is an integral part of a GANA Decision Element (DE).

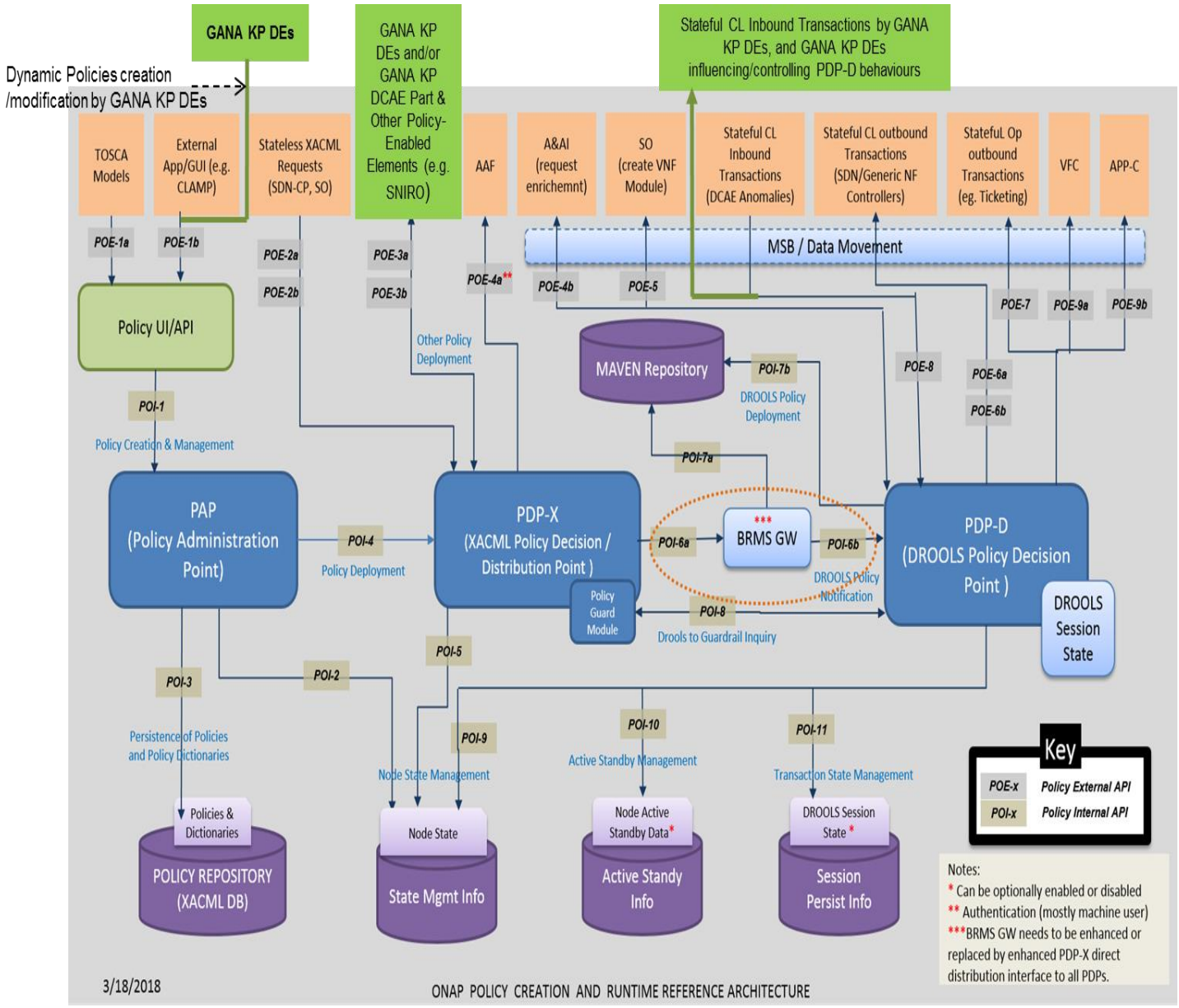

Figure 16: ***How the GANA Knowledge Plane should integrate (interact) with the ONAP Policy Management Framework***

6.6.2 Option-2: ONAP Policy Architecture (Policy Management) Framework considered as being an integral part of the Knowledge Plane

According to in ETSI TS 103 195-2, Policy Execution Engines such as PDP and associated Policy servers should be considered as integral parts of the Knowledge Plane, while some policy design and conflict resolution framework may be part of Automated Management Tool Chain Framework that is external to the Knowledge Plane and is used to provide inputs to the KP. As the networking industry will continue to move to an era where Knowledge Planes will take over the roles of traditional OSS's and other systems such as EMS'/NMS's as described in ETSI TS 103 195-2, a whole Policy Architecture (Policy Management) Framework may be considered as an integral part of the Knowledge Plane. And so it remains an open option for the consideration of the ONAP Policy Architecture (Policy Management) Framework being integrated as integral part of the Knowledge Plane. But still with that option, the integration and interaction of KP DEs with PAP, PDP-X and PDP-D (with all the

three components being KP components as well) would still follow the approach described in the Option-1 on ONAP Policy Architecture (Policy Management) Framework interworking with the Knowledge Plane components but being considered external to the Knowledge Plane.

6.7. How some ONAP Components can be used to Implement a GANA ONIX Server and possibly ONIX's Federated Information Servers as well

The following figure (**Figure 17**) illustrates how some ONAP Components can be used to implement a GANA ONIX Server and possibly ONIX's Multiple Federated Information Servers as well.

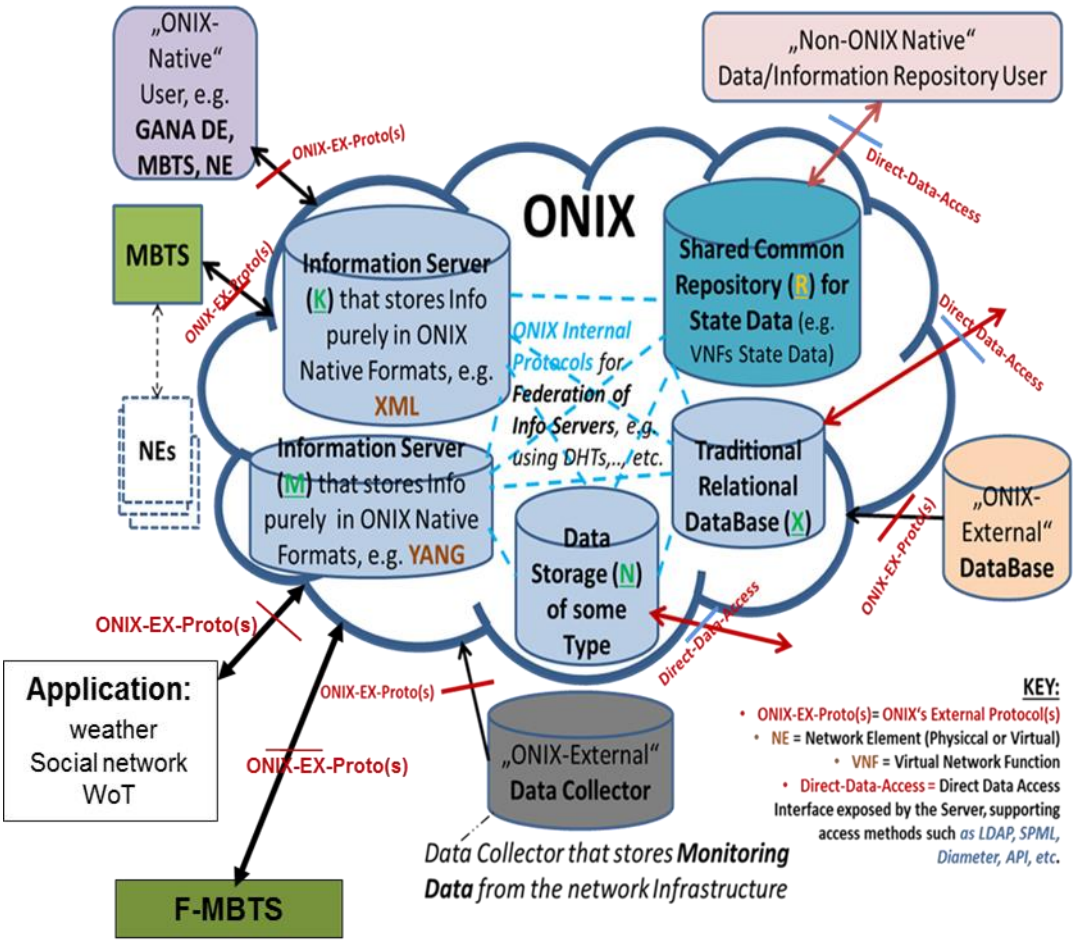

Figure 17: ***How some ONAP Components can be used to Implement a GANA ONIX Server and possibly ONIX's Multiple Federated Information Servers as well***

ONIX as Real-Time Inventory:

- Useful for Inventory awareness of changes over time, including Cache of Historical Decisions made by GANA Knowledge Plane DEs and their mappings to contexts/situations encountered
- Near real time updates and extended auto-discovery, thanks to Publish/Subscribe Paradigm employed by ONIX to provide its services

- Cognitive Algorithms running on some ONIX Information Servers for the management of certain information and knowledge make ONIX a Cognitive inventory
- ONIX can be used for dynamic maintenance of network slice configurations in the case of 5G

ONAP Capabilities of relevance to ONIX:

- Based on the ONIX Specification in ETSI TS 103 195-2 [2] implementers need to elucidate on the need to check and discuss how the AINI in ONAP is implementing some GANA ONIX Server Features
- ONAPs' Active & Available Inventory (A&AI) can be considered as ONIX Server as it stores the following information that could be subjected to the "Publish/Subscribe" ONIX services and possibly the federation with other types of info stored on other types of ONIX servers:
  - **Real-time topology map** with context views of virtual networks, services & applications
  - **Relationship context** between components & the network fabric & infrastructure, using the network resources as the database records due to their dynamic nature
  - **Provides a registration method** used to discover & maintain services & resources

6.8. Other thoughts on GANA Knowledge Plane implementation using ONAP and how to extend ONAP to fulfil GANA Requirements

For Further Study: Implementers would need to further examine the DCAE in ONAP to see the extent to which the DCAE is implementing certain functionalities of the **GANA Knowledge Plane such as DEs, MBTS and ONIX features. Some of the Questions for investigation by implementers are:**

- Is the **AINI in ONAP** implementing some of the functionalities specified for the GANA ONIX? If so, how can the ONAP component be evolved to be used to implement an ONIX Server and an ONIX system as presented earlier in this paper?
- Review the proposal on how DCAE Analytic Applications and DCAE Platform collectively help to implement the GANA Knowledge Plane overall to see if the Northbound Interface of the DCAE need to be enhanced in order for DEs to interact with the DCAE, bearing in mind also that the MBTS function (AMC-MBTS) could be considered as the Southbound Interface implementation of the DCAE.

6.9. "Knowledge Plane-Driven" Orchestration—based on Business Goal Incentives or Autonomic Service Assurance by the KP through Selective Multi-Layer Programming Targets by KP Autonomics

ETSI TS 103 195-2 provides a characterization of the Knowledge Plane (KP) concept, including various incentives that KP algorithms implementers may consider in implementing the "intelligence" of a GANA Knowledge Plane of a certain scope/width of operations in interacting with various management and control systems and data/event sources. As described in ETSI TS 103 195-2 some incentives for KP Autonomics may be business oriented while others may be technical (e.g. reactive and proactive autonomic resilience). In order to achieve both ***reactive and proactive autonomic resilience*** in service delivery by the network (e.g. 5G Network Slice delivery), a GANA Knowledge Plane can exercise the following operations indicated on the Figure 11 in [17], depending on KP DEs' Algorithms that implementers may determine as viable for the KP to implement autonomic remediation strategies that can be selectively applied by the KP issuing commands to orchestrators or SDN Controllers. The KP's autonomics algorithms derive(plan) the kind of service remediation strategies against service failure or performance degradation, including the timing of the KP's actions for executing the strategies as well as the programmatic interfaces through which the KP can execute the service remediation strategies for autonomic service assurance.

NOTE: White Paper No.3 of this ETSI 5G PoC [17] provides implementation illustration on the subject "Knowledge Plane-Driven" Orchestration—based on Business Goal Incentives or Autonomic Service Assurance by the KP by Selective Multi-Layer Programming Targets by KP Autonomics.

6.10. Implementation Options on the role the Knowledge Plane (KP) can play in Network Service Configuration and Autonomic Service Assurance in ONAP environments

There are various roles the Knowledge Plane can play in Network Service Configuration and Autonomic Service Assurance in ONAP environments as follows:

1. **Knowledge Plane participating in both**, the **initial configuration of a newly created network service** and in **autonomic service assurance** of the instantiated (running) network service(s). In this KP mode of operation, policies that are meant to govern the network infrastructure elements' (PNFs/VNFs) behaviors are supposed to be provided as inputs to the KP DEs so that the DEs generate low level configuration data for the network infrastructure elements (PNFs and VNFs) and their internal DEs and Managed Entities (MEs) from the input policies, i.e. the KP DEs can act as "interpreters" of the input high level policies and application intents (as described in ETSI TS 103 195-2 [2]) defined by the human using the ONAP Policy Design and Policy Conflicts resolution framework. The low level policies and configuration data for the PNFs/VNFs should then be disseminated to the PNFs/VNFs through some means possible such that the configuration of the PNFs/VNFs is brought into effect. Having to participate (play a role) in the (re)-configuration of a network service, the KP then plays an additional role of performing autonomic service assurance of the service(s) by reactively and proactively orchestrating and tuning all the necessary resources and parameters that enable to assure acceptable service performance and security and guarantees for SLAs (Service Level Agreements). Such Autonomic Service Assurance include dynamically generating new policies for adaptation of network infrastructure configurations to business goal changes, context changes for the network, workload changes, challenges such as manifestations of faults/errors/failures/threats and service(s) performance degradations, while the KP DEs continue to respect the input policies and goals that were supplied by the human operator as a way to govern (constraint) the "operating region" of the KP DEs that they should adhere to.
2. **Knowledge Plane restricted to participating in autonomic service assurance** of the instantiated (running) network service(s) but not directly being involved (interfering) in the initial configuration of a newly created network service, though the KP DEs can be made to act as recommenders for optimal configurations by computing the optimal low level configurations for low level DEs and MEs in PNFs and VNFs based on the input policies supplied to the KP DEs by the human operator (though the relevant automated management tools) without the KP autonomously applying the computed configurations. In this mode of KP operation, the initial configuration of a service or PNF/VNF may be performed by other management tools/systems the human operator may choose to use and then activate the KP to be restricted to only then performing closed-loop (autonomic) service assurance of the service(s).

NOTE-1: In both option cases on the KP implementation and operational modes, the KP should be made to consume the human supplied inputs (including governance policies, business goals of the network and application intents, etc.) and interpret them to compute the optimal configurations that can then be applied to low level DEs and MEs in PNFs and VNFs either automatically by the KP or as recommendations that the human operator may choose to apply to configure the network. Also, in both cases, regarding autonomic service assurance, the KP exercises (re)-programming of network resources and parameters selectively using the most viable means possible to program the network via the appropriate management and control layer(s), e.g. via the OSS, Orchestrator, MANO stack, SDN controller layers, or other programmability layer exposed to the KP DEs.

NOTE-2: ETSI TS 103 195-2 [2] describes scenarios on how Knowledge Planes may replace OSS's and other traditional management systems into the future, while early implementations of Knowledge Planes should interwork with existing traditional management systems as described in ETSI TS 103 195-2 [2].

7. Using ONAP Components to Implement GANA Knowledge Planes and Advancing ONAP accordingly—using "*C-SON – ONAP Architecture*" as illustration on GANA Knowledge Plane for the RAN—by Cellwize

7.1. DCAE Platform role in C-SON (Centralized Self-Organizing Network functions), Network Slicing, ONAP for Designing GANA Components, and ONAP Architecture for Slice Management

The role of DCAE Platform and Analytics Applications in C-SON implementation for Multi-RAT RAN (Radio Access Network) is based on the understanding that ONAP DCAE Analytic Applications and DCAE Platform collectively help implement the GANA Knowledge Plane.
The ONAP **DCAE Platform** consists of several functional components that might **be used as data inputs for C-SON**:

- **DCAE Streaming:** Radio Measurements, Cell KPIs, Core Network KPIs
- **DCAE Analytics**: User Classification, Enrichment Data
- **Engineering Rules & Policies**: SLA target, NSI (Network Slice Instance) priority level, policies, network slice template

The following figure (**Figure 18**) illustrates the ONAP Architecture for Slice Management, and how ONAP DCAE Analytic Applications and DCAE Platform collectively help implement the GANA Knowledge Plane (as C-SON in the case of GANA Knowledge Plane for RAN).

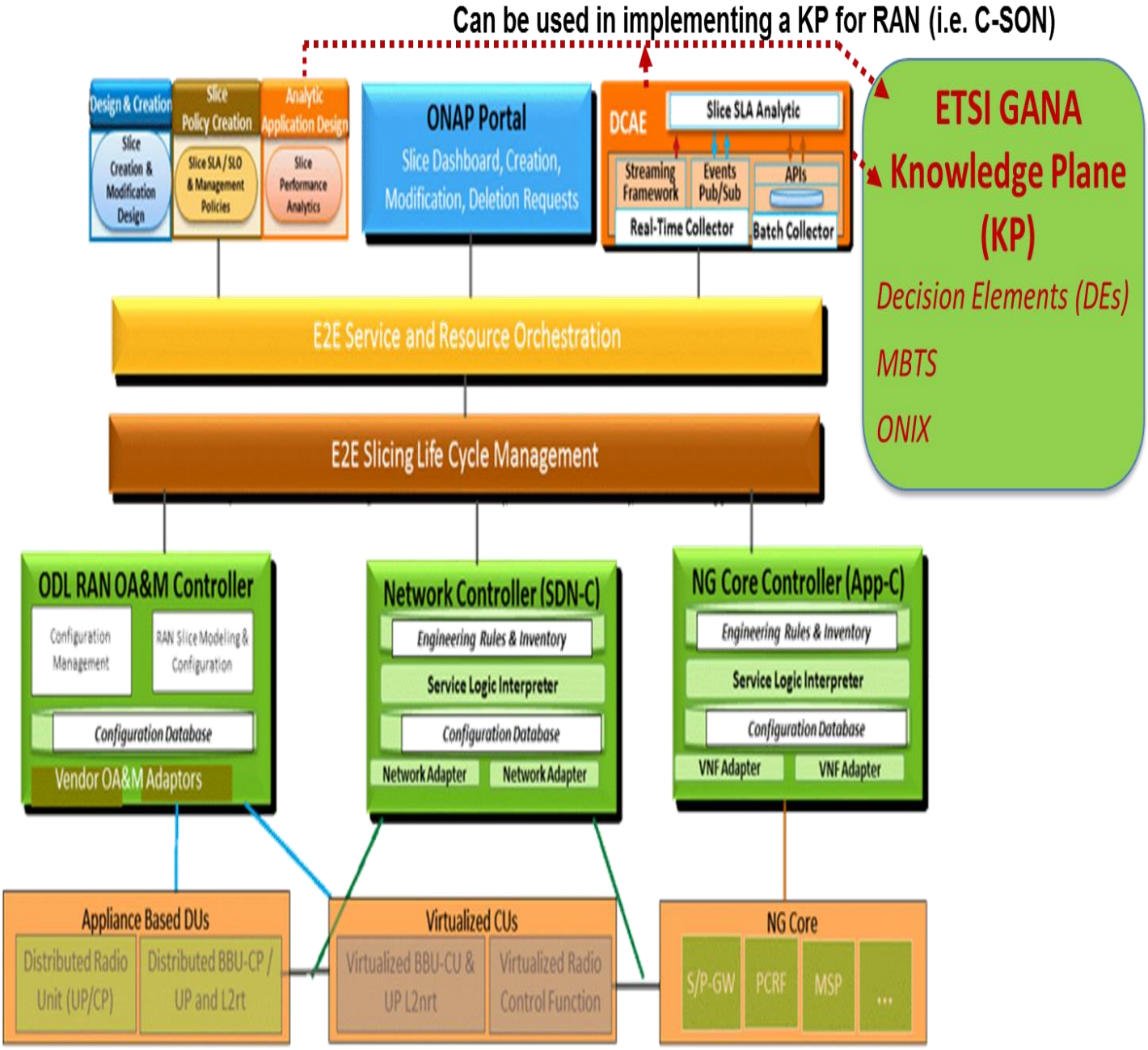

Figure 18: ***ONAP Architecture for Slice Management, and ONAP DCAE Analytic Applications and DCAE Platform collectively help implement the GANA Knowledge Plane (e.g. KP for RAN—namely C-SON)***

7.2. ONAP Architecture for RAN Deployment

The following figure (**Figure 19**) illustrates an ONAP Architecture for RAN Deployment demonstrated in an implementation in this PoC [3].

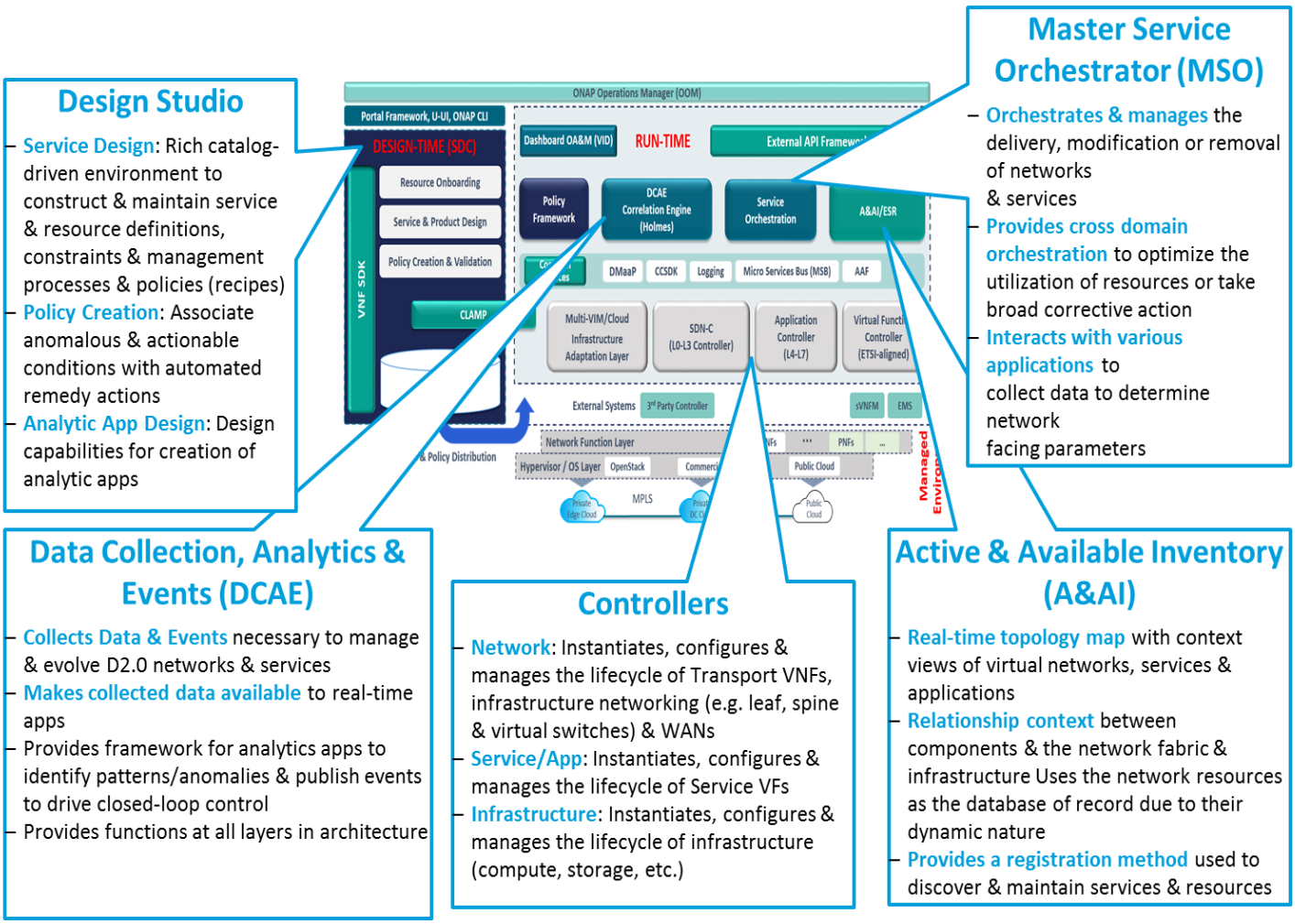

Figure 19: ***An ONAP Architecture for RAN Deployment***

The following figure (**Figure 20**) illustrates an ONAP Architecture for Slice Management, with positioning for the ETSI GANA Knowledge Plane and AMC-MBTS Functionality.

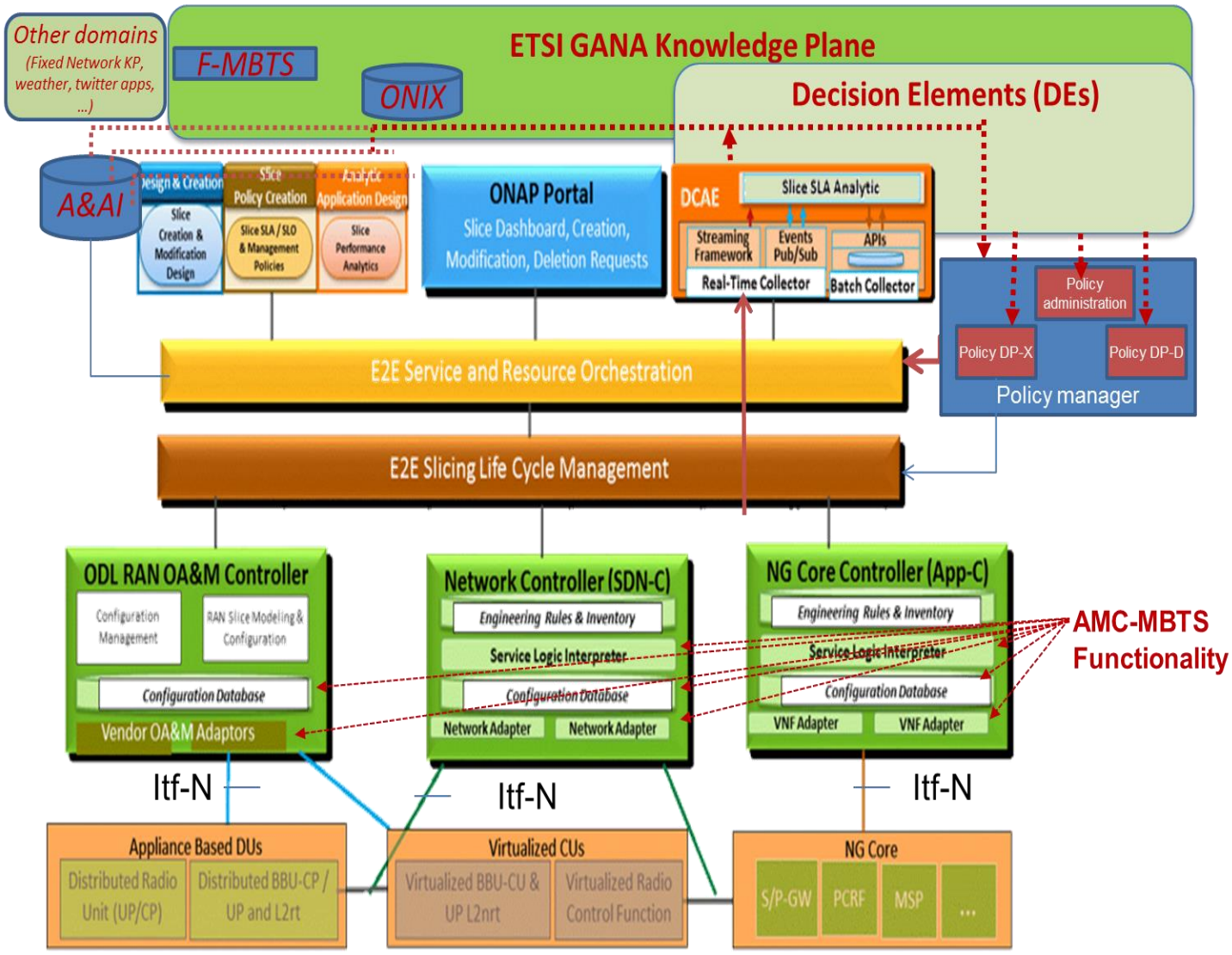

Figure 20: ***ONAP Architecture for Slice Management, with positioning for the ETSI GANA Knowledge Plane and AMC-MBTS Functionality***

7.3. ONAP Mapping of MBTS for 5G Slice Service Assurance

The following (**Figure 21**) illustrates the ONAP Parts that can be used to implement an MBTS for use in 5G Slice Service Assurance by GANA Knowledge Plane for RAN (C-SON).

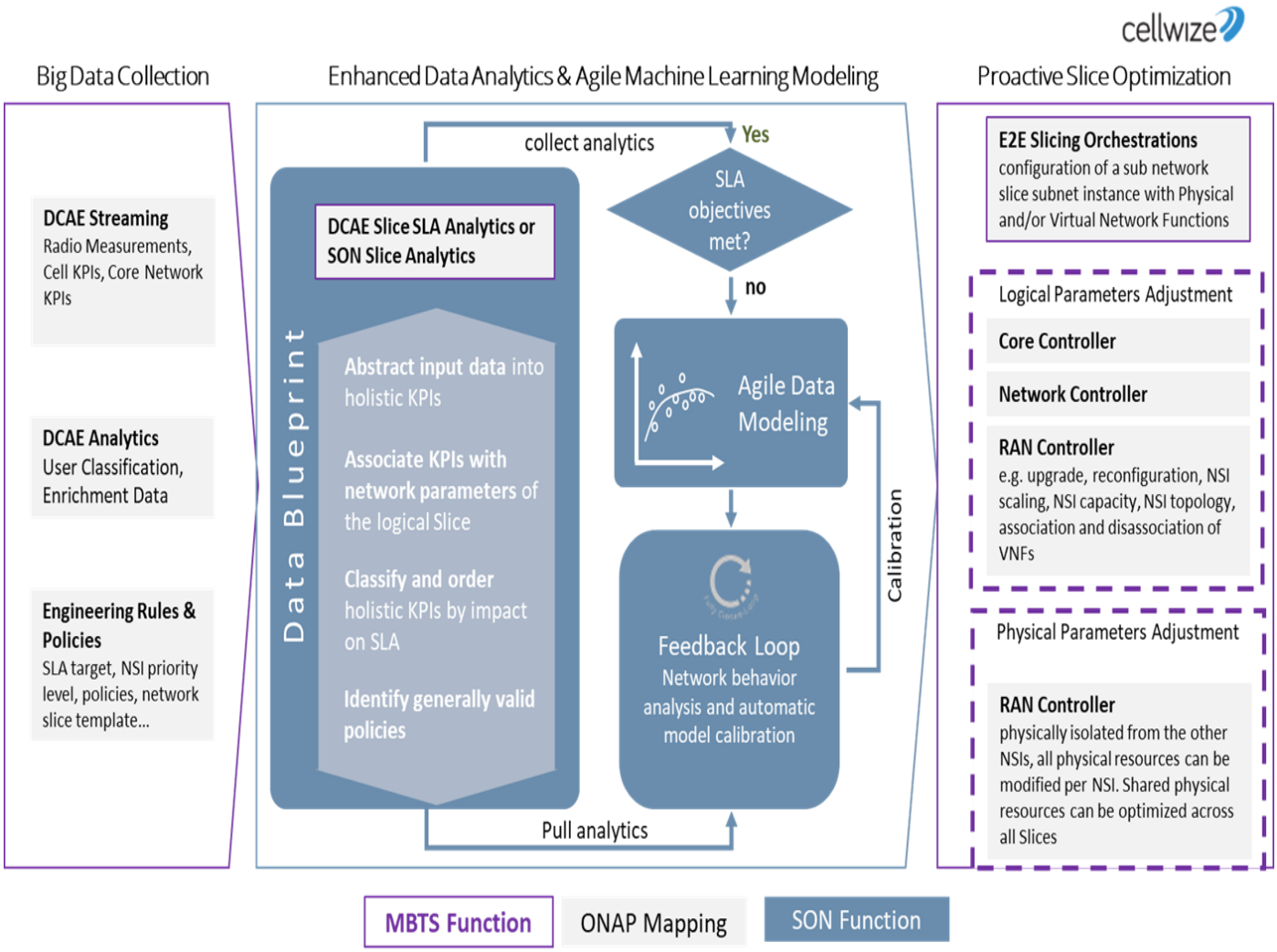

Figure 21: ***Illustration of the ONAP Parts that can be used to implement an MBTS for use in 5G Slice Service Assurance by GANA Knowledge Plane for RAN (C-SON)***

7.4. Assumptions Regarding ONAP

The following are assumptions regarding ONAP capabilities as at the time of the time the Demo-2 of the ETSI 5G PoC was executed within the timeframe of February 2018:

- ONAP supports the complete lifecycle management of network slicing including
  - Lifecycle management of PNFs
  - Enhanced SDC to support modeling of network slicing
  - AAI extensions for slicing data models
  - Enhanced orchestrator to manage lifecycle of network slices (may be a new orchestrator)
- ONAP supports edge cloud deployment
- Optimal placement of 5G VNFs
- Policy-driven performance optimization capabilities
- Near real-time data collection and processing
- C-SON reconfigures slices during run-time to assure SLA and optimize resources
  - Sub-slice instantiation

- Logical parameter adjustment
- Physical parameter adjustment

7.5. Use Cases for SON & ONAP Coordination

The following are some of the Use Cases that were considered within the scope of the Demo-2 of the ETSI 5G PoC that was executed within the timeframe of February 2018:

- E2E 5G Slice Service Assurance (RAN and Core)
- 5G White space/unlicensed spectrum management
- SON management of disaggregated RAN components
- Online PnP
- New techniques for HetNet load balancing across RATs (Radio Access Technologies)
- Datafill & consistency assurance

8. Using ONAP with other Open Source Components to implement GANA Knowledge Planes for other Network Segments/Domains other than the GANA Knowledge Plane for RAN (C-SON)

8.1 Overview

While this White Paper has focused on exploring how to use ONAP and extensions that may be required thereof to implement a GANA Knowledge Plane, there are other Open Source Projects that can be used together with ONAP in implementing GANA autonomics components (such as the Knowledge Plane components defined by ETSI TS 103 195-2). While ONAP can be used in implementing GANA Knowledge Planes, there are other aspects on GANA autonomics that could complementarily be designed, simulated and/or validated (e.g. state machines validations) by other tools. For example, the ACUMOS project could offer certain capabilities of relevance in designing DEs' AI (Artificial Intelligence) algorithms for AMC. For example, ACUMOS can offer capabilities around Artificial Intelligence (AI) in DE (Decision Element) Autonomics Algorithms, for DEs at specific GANA Levels of Abstraction of Autonomics/Self-Management (with focus on the most significant GANA Levels 2, 3 and 4, i.e. the most important levels that can easily be implemented as overlay software on top of existing protocols stacks without changing anything in the protocols of the network protocol stacks—since embedding autonomics (closed-loops) in individual protocols should be rather avoided while still benefiting from higher level autonomics as discussed in ETSI White Paper No.16 [1]).

This section does not seek to provide a detailed study on how various open source projects can be used complementarily with ONAP in implementing GANA Knowledge Planes. Such a detailed study on the various open source projects is outside the scope of this paper, and remains an important subject that should be addressed. However, the following are simply guiding insights on a selected few Open Source Projects on how they can complementarily be used together with ONAP on implementing GANA autonomics.

8.2 Exploring Capabilities in the ACUMOS Open Source Project

ACUMOS [16] offers some capabilities that implementers of GANA autonomics can consider. For example, while considering the principles and insights that are described in ETSI TS 103 195-2 regarding DE-to-ME Mappings and the various approaches that can be taken in designing DE internal logic, control-loop structures and autonomics algorithms, some of the capabilities in ACUMOS that should be considered in designing DEs are as follows:

- Tools for building neural nets, classifiers, clustering algorithms and other types of AI components [16]
- Data-driven machine learning models [16]

8.3 Exploring Capabilities in the ETSI OSM (Open Source MANO (Management and Orchestration)) Open Source Project

Of particular importance for consideration are two aspects:

1. the integration of GANA Knowledge Plane with MANO and other management and control systems (including orchestration systems)
2. GANA Autonomics in NFV MANO stack as illustrated on **Figure 3** on Multi-Layer Autonomics and the integration of the GANA Knowledge Plane with Orchestrators, SDN Controllers, Big-Data Analytics for AMC, and OSS/BSS systems, and also as described in more detail in ETSI TR 103 473.

8.4 Other Open Source Projects for consideration on either design tools and principles that could be considered/applied to designing some GANA components, or Integration of those Open Source Platforms with GANA Functional Blocks

Other Open Source Projects for consideration include the following:

- **OPNFV** [12]: On GANA Autonomics in NFV MANO stack as illustrated **Figure 3** on Multi-Layer Autonomics and the integration of the GANA Knowledge Plane with Orchestrators, SDN Controllers, and OSS/BSS systems, and as described in more detail in ETSI TR 103 473.
- **ONOS** [13]: On SDN Controller Integration with GANA as described in ETSI White Paper No.16, ETSI TS 103 195-2 and ETSI TR 103 473.
- **OpenDayLight** [14]: On SDN Controller Integration with GANA as described in ETSI White Paper No.16, ETSI TS 103 195-2 and ETSI TR 103 473.
- **TIP (Telecom Infrastructure Project)** [10]: On consideration of GANA Knowledge Planes designs and deployments for specific network segments (Access network, X-Haul/Backhaul network, Core network) by leveraging open source and other essential outputs from the so-called Strategic Network Areas projects in TIP. In such network segment specific GANA Knowledge Planes design and developments, the ETSI TR 103 473, ETSI TR 103 404, apart from ETSI TS 103 195-2, should be used by implementers of the GANA Knowledge Planes and the low level autonomics (DEs) that could be injected into NEs/NFs.
- **Broadband Forum (BBF) CloudCO** & OpenBroadband Open Source [11]: On GANA in BBF Open Source Project CloudCO and Open BroadBand, based on ETSI TR 103 473. The ETSI TR 103 473, apart from ETSI TS 103 195-2, should be used by implementers of the GANA Knowledge Planes and the low level autonomics (DEs) that could be injected into NEs/NFs of BBF (Broadband Forum) network architectures. For example, in design and implementation of a *GANA Knowledge Plane for the CloudCO and the BAA (Broadband Access Abstraction) Layer as implementation of the MBTS function*.

9. Federation of GANA Knowledge Planes for E2E Autonomic (Closed-Loop) Service Assurance across various network segments/domains

E2E Autonomic Service Assurance of E2E Network Services (including 5G Network Slices) shall be achievable through the ***Federation of GANA Knowledge Planes (KPs) for specific network segments/domains***, and ***complemented by lower level autonomics in Network Functions(NFs),*** for achieving "*Holistic E2E Multi-Domain State Correlation and adaptive resources programming*" by the **GANA KPs** for specific network segments such as ***Access***, ***X-Haul/Backhaul***, and ***Core Networks*** *(as illustrated below (see Figure 22)), and the federation of the KPs across a chain of network segments that form an end-to-end (E2E) scope of some sort. The scope of Federation of Knowledge Planes may be extended to cover other domains beyond the core network, such as a Data Center Network hosting some Telco-Cloud Network Functions or even IT Applications.* Service Providers seek to deploy such a ***Framework for E2E Autonomic (Closed-Loop) Service Assurance for Network Services*** as illustrated below and in ETSI TR 103 404 and the Reports available at [3]. ETSI TS 103 195-2 provides guiding principles that help implementers to implement Federation of GANA Knowledge Planes across multiple domains (including administrative domains). ETSI TR 103 404 and ETSI TR 103 473 provide insights on Federation of GANA Knowledge Planes for various network domains/segments that are very useful for implementers. For more information and PoC results and requirements on

Federation of GANA Knowledge Planes for E2E Autonomic (Closed-Loop) Service Assurance across the various network segments/domains readers should also refer to [3][4]. The broader picture on the value of Federation of GANA Knowledge Planes to achieve E2E Autonomic (Closed-Loop) Service Assurance across various network segments/domains is covered in [5]. **NOTE:** Federation of KPs also enables them to achieve other E2E Autonomic Management and Control (AMC) targets/objectives (determined by the various types of DEs in the Knowledge Plane) such as E2E Autonomic Security Management and Control targets/objectives across various network segments/domains, other than E2E Autonomic Service Assurance objectives.

To achieve autonomic service assurance, each GANA Knowledge Plane for a particular network segment uses mappings of QoS (Quality of Service) Classes and associated SLAs (Service Level Agreements) parts of the global SLAs that apply to the network segment under its responsibility to determine the autonomic (closed-loop) operations that the KP needs to apply to its network segment resources and parameters programming to guarantee the SLAs parts for the particular network segment, while the KP listens for reports and synchronization messages from KPs of the other segments to determine collective actions that should be performed by the KPs to guarantee global SLAs for Slices and their constituent sub-services. As described earlier, each KP for a particular network segment is fed with various data/information and events from various data sources and event sources of relevance to the picture (visibility) the performance and telemetry/monitoring data (e.g. KPIs (Key Performance Indicators)) concerning Network Services under its autonomic service assurance responsibility. As illustrated on Figure 22 and in [5], Access Network Slices are under the control of KP for Access Network Segment, X-Haul Slices are under the control of KP for X-Haul Transport Network Segment, and Core Network Slices are under the control of KP for the Core Network.

NOTE: According to GANA principles specified by ETSI TS 103 195-2[2], the Autonomic Manager Component that would be the one responsible for dynamic steering of resource (re)-allocation per slice, preemption and reprioritizing slices, resource adaptation per slice for maximal fairness, throughput, or SLA compliance enforcement, including Admission Control for QoS provisioning within a network segment as a domain, as well as autonomic operations required to guarantee QoS for Slices and flows they carry, is the ***QoS-Management Decision Element (DE) of the Knowledge Plane (KP) responsible for the network segment(domain)***—e.g. KP for Access Network. As specified in the GANA specification (ETSI TS 103 195-2), the *KP level QoS-Management-DE* policy-controls GANA level-2 QoS-Management-DEs in certain Network Elements/Functions (NEs/NFs) located at certain points in the network segment (e.g. at the borders with other network segments/domains) in order to implement strategies for Autonomic QoS Provisioning and Guaranteeing within the segment/domain, while the KP interworks(federates) with KPs for other network segments/domains to realize the global objectives of E2E Autonomic QoS Provisioning and Guaranteeing.

Regarding telemetry, telemetry/monitoring data concerning slices and their sub-services, Out-of-Band Monitoring solutions (such as the one presented in White Paper No.3 [17]) and other monitoring techniques (including telemetry data made available by network elements and in-band monitoring protocols) all complement each other in providing the visibility required by GANA Knowledge Planes, but all these telemetry techniques and data collection and dissemination methods need to be deployed cost-effectively by the network operator. In network segments that are based on IPv6 as transport protocol, there are IPv6 features that are expected to bring value to Service Assurance for 5G Slicing and can be leveraged, e.g. the use of Extension Headers in grooming telemetry information along paths in the network and using the telemetry information in driving adaptive (autonomic) service assurance of slice specific traffic flows by way of adaptive QoS tuning by the GANA Knowledge Plane(s) responsible for the particular network segment(s).

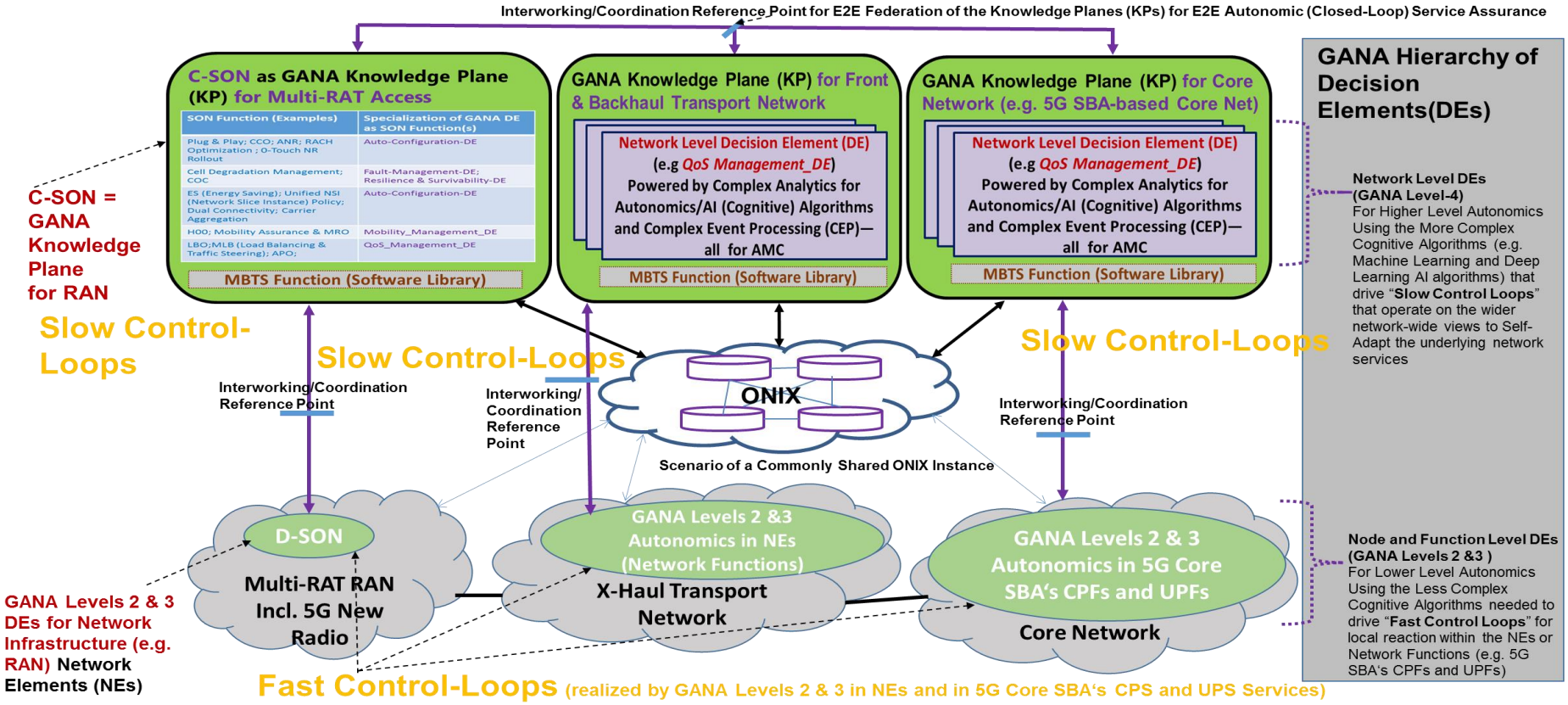

Figure 22: Framework for E2E Autonomic(Closed-Loop) Service Assurance of Network Services through the Federation of GANA Knowledge Planes (KPs) for various segments: RAN (C-SON), Front-/Backhaul, Core Network, etc., and complemented by lower level autonomics in Network Elements (NEs) or Network Functions(NFs)

10. On APIs (Application Programming Interfaces) that need to be considered in implementing a GANA Knowledge Plane

There are various types of APIs that should be considered and implemented so as to enable to implement GANA Knowledge Planes and to enable to implement Federation of GANA Knowledge Planes for Federated Autonomic & Control across Domains (both technical and administrative). The sub-sections below describe the categories of the APIs that should be considered by implementers, including those that would use ONAP to implement Knowledge Planes, and also those that would use other open source products such as OSM [15], ACUMOS[16], ONOS[13], OpenDaylight[14], OPNFV[12], TIP [10], BBF CloudCO [11] and other open source products, to implement Knowledge Plane DEs or interfaces between the GANA Knowledge Plane and other systems such as SDN Controller, NFVO MANO components, Service Orchestrators, Network Service Orchestrators, Application Orchestrators, Big-Data driven analytics for AMC, OSS/BSS, etc.

10.1 Requirements for APIs Necessitated by the Unified Architecture for ETSI GANA Knowledge Plane, SDN NFV, E2E Orchestration, Big-Data driven analytics for AMC, OSS/BSS

ETSI TS 103 195-2[2] specifies APIs that should enable to integrate ETSI GANA Knowledge Plane, SDN, NFV, E2E Orchestration, Big-Data driven analytics for AMC, and OSS/BSS systems (or configuration management systems in general). Implementers should consider implementing such APIs if there are no APIs already available to enable to integrate a GANA Knowledge Plane with other management and control systems. For example, SDN Controllers, Orchestrators and OSS/BSS systems on the market today already may be implementing NorthBound APIs that can be used by the overlay implementation of a GANA Knowledge Plane to provide for the autonomics based intelligence as described earlier in this paper.

In addition to those APIs, the APIs described in the subsequent sub-sections below should be considered by implementers as they are complementary to those specified in ETSI TS 103 195-2[2].

10.2 APIs in the context of ONAP for GANA Knowledge Planes Implementations (APIs between KP DEs and DCAE, KP DEs and ONAP Applications, etc.)

There are APIs that should be introduced if there are no APIs in ONAP already that can enable to integrate GANA Knowledge Plane components with ONAP Platform's components (in reference to **Figure 12**).

API	Provider of the API
1. *KP-DEs_and_DCAE_Interaction_API* **NOTE:** This could be the already available DCAE NorthBound Interface of DCAE	*DCAE*
2. *KP-DEs_and_ONAP-Applications_API*	*ONAP Applications (e.g. DCAE Analytic Applications)*

NOTE-1: Such APIs should be consumed via the *OtherInteraction_Interface* of a ***DE Model*** defined and described in ETSI TS 103 195-2[2].

NOTE-2: In addition to these APIs, ONAP components such as DCAE should be able to consume and use the ONIX's publish/subscribe services offered by ONIX.

10.3 APIs in the context of Federation of GANA Knowledge Planes for Federated Autonomic Management & Control across Domains (Network Segments)

ETSI TS 103 195-2[2] provides details on how to articulate (achieve) E2E Federated GANA domains of management and control architectures for inter-domain autonomics, as well as the associated AMC Federation Reference Points and what could be communicated on those reference points to effect federated autonomics. Federated autonomics, through cross-domain cooperation of GANA autonomics Functional Blocks (FBs) in different domains, e.g. Knowledge Planes, can be implemented via the use of APIs that can form a Broker of some sort as indicated on the figure below (**Figure 23,** and extract from ETSI TS 103 195-2).

In general, when taking into consideration cross domain autonomics, two or more Decision Elements (DEs) designed to form peers across a Reference Point of nature "DE-to-DE interface across multiple network elements/devices" need to discover the following types of information concerning their peers:

- **Domain Type(s): DT(s)**
    - Technical or administrative, of which the DE is member and is willing to share this information **(subject to security and trust policies)**
    - Regarding **Discovery of a "technical" domain** to which a DE belongs (or is able to orchestrate and autonomically manage and control Managed Entities (MEs) of relevance to DE-to-DE federation), the GANA Model includes the concept of **Capability Model (**and its **self-description and publishing** by a DE) through which information about a "technical domain" is encapsulated, as described in ETSI TS 103 195-2[2].
    - A DE should **aggregate capabilities** of its assigned Managed Entities (MEs) and advertise the descriptive information on capabilities when required **(subject to security policies**). For example, a ***Function-Level Routing-Management-DE*** in a routing device running two routing protocols e.g. OSPF and BGP, would indicate the routing protocols (as its Managed Entities) under its control, in its Capability Model description
- **Domain Identifier: DId**: Administrative domains may have Domain Identifiers assigned by the **governing authority/entity** following some scheme of choice.

Requirements associated with Federation Reference points between different Domains:

- DEs use such information **(DT and DId)** to **verify against security and trust policies**, and to behave accordingly in the way they configure their respective Managed Entities (MEs) to fulfil the required network behaviours across domain boundaries involved in the federated autonomics
- The exchange of such information **(DT and DId)** may possibly be **restricted to** the **Node-Main-DEs discovering** and **exchanging** such information **on-behalf of the lower level (Function-Level) DEs** that then use the information to behave accordingly in the way they **provision an autonomic management and control service across the domain boundaries involved** (see concept of "Node-Main-DE in Figure 1 and in ETSI TS 103 195-2[2]
- The **Federation Rfps** involving DEs in network infrastructure elements (NEs/NFs) need to be carefully designed as they may be required to fulfil requirements for proactive and fast reaction by the DEs. **Characteristic information** and **operations** of federation Rfps need to be **semantically formalized** in the **same way** between two different domains
- **At the Knowledge Plane level**, between **ONIX instances (Logically centralized Shared Data / Knowledge Repository)** belonging to different domains or between DEs belonging to different domains, an **MBTS (Service Translation) instance (F-MBTS)** may be used to translate the

information retrieved within a domain to information representation and presentation format(s) required by the peer domain

- Reference (Rfp) **point between DEs within different administrative domain** within the **same GANA-Level**. This Rfp may embed **security and trust mechanisms in the DEs** or in **separate function or mechanism** as may be available for that purpose of DE-to-DE interactions
- A dedicated reference point between administrative domains may be defined when GANA is instantiated in particular reference architecture (e.g. access and core mobile network), BBF Architecture, 3GPP Architecture
- In some other case, **interworking functions** may be specified with MBTS functions and **broker functions** used to specify and interwork distributed peer to peer KPs within different administrative domains.

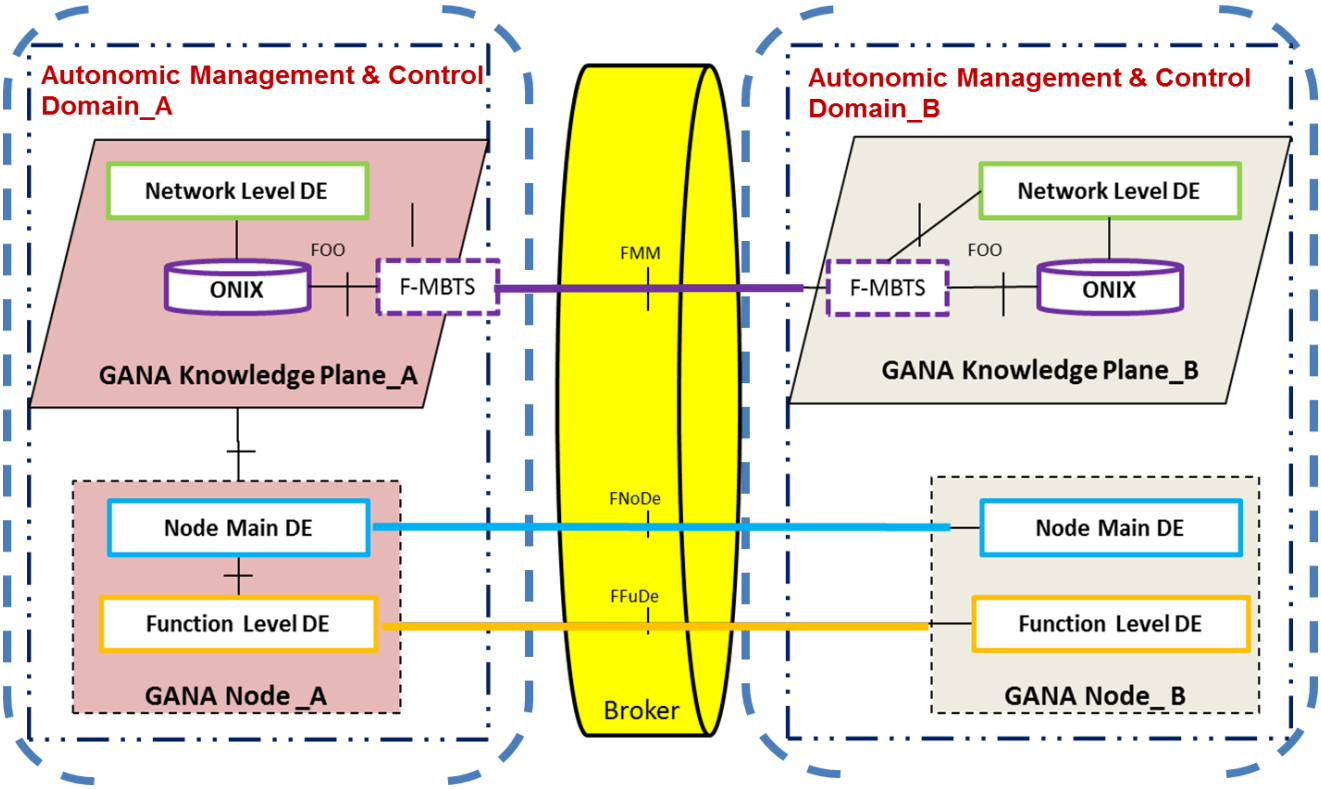

Figure 23: ***Federation of GANA domains of management and control architectures for inter-domain autonomics***

ETSI TS 103 195-2[2] defines and describes Federation Reference points at GANA's three abstraction levels of self-management functionalities of most importance, namely Rfps (**FFuDE, FNoDe, and FMM**) between Function/ Node/ Network level DEs, respectively, within different Domains.
ETSI TS 103 195-2[2] defines and describes the FMM Federation Reference Point: Knowledge Plane-to-Knowledge Plane, whereby MBTS services may be required.

Examples of Information that can be exchanged between Domains, e.g. between GANA Knowledge Planes across multiple Domains—information that may need to be exchanged between Peer Domains are illustrated below:

- **KPIs (examples):**
  - *Trust Levels (as measure of trustworthiness)*
  - *Threats Counts of potential impact "**To**" Peer Domain and Severity*
  - *Threats Counts of potential impact "**From**" Peer Domain and Severity*

- *Aggregate state of the Domain in terms of Workload or Load Levels*
- *Weights that are indicative of willingness of the Domain to deliver certain services (e.g. transport services)*
- *Many Other Types of KPIs that function as security indicators can be identified and defined*

- ***Other Types of Information***
  - *Domain Type(s) : DT(s)*
  - *Domain Identifier : DId*
  - *Synchronization of actions across multiple GANA Knowledge Planes*
  - *Security event information, e.g. Detected Threats/Incidents that may impact Peer Domain*
  - *Trust Models Information*
  - *Security SLA Violations unresolved*
  - *Load Situations and other types of Situations (e.g. as described in ETSI TR 103 404 and ETSI TR 103 473)*
  - *Various Types of Information and State Information that enable Multi-Domain State Correlation and resources programming by the GANA KPs for the collaborating Domains (e.g. Access, X-Haul (Fronthaul and Backhaul), Edge/MEC (Multi-Access Edge Computing), Data Center (DC), IP Backbone, and Core Networks, etc.), as outlined in ETSI TR 103 404 and ETSI TR 103 473 for examples.*

11. Vendors' Business View of the Overall 5G PoC: Supplying ONAP based GANA Knowledge Planes Software/Platforms for E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices

The ETSI White Paper No.16 describes the two categories that determine the actors or players the GANA model is addressing, namely: Suppliers (vendors) of GANA Functional Blocks (FBs); and Provider of assets required by the developers of GANA Functional Blocks (FBs). ETSI TC INT AFI WG is a provider of assets (such as Specifications and Technical Reports on Use Cases Scenarios and Requirements for introducing GANA Autonomics in Network Infrastructure Elements/Functions of specific standardized reference network architectures (e.g. BBF (Broadband Forum architectures, 3GPP architectures, etc.) and their associated management & control architectures and systems) required by the developers of Autonomics Functional Blocks (FBs), by providing ETSI TR documents on how to introduce GANA autonomics in network architectures such as Broadband Forum (BBF) (see ETSI TR 103 473) and 3GPP Backhaul and Core Network Architectures (see ETSI TR 103 404). The business value described in ETSI White Paper No.16 for Suppliers (solution vendors) of GANA Functional Blocks (FBs) concerns the following players: ISVs (Independent Software Vendors); Network Traffic Monitoring Solution Vendors, and Networking Equipment Manufacturers. All of such players can be suppliers of GANA AMC software such as Decision Elements (DEs) and their associated vendor differentiated autonomics Algorithms (e.g. Artificial intelligence for dynamic configuration and control of resources and parameters); GANA MBTS; GANA ONIX; and GANA Knowledge Plane Software in general.

Remark: Demo-2 was mainly focused on Suppliers of GANA conformant Autonomic (Closed-Loop) Service Assurance pertaining to the GANA Knowledge Plane for the RAN (Multi-RATs) and Backhaul Transport and Core Networks. While Demo-3 and subsequent Demos in the PoC will consider the following scope: Suppliers of Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring and Feeding of Knowledge into the GANA Knowledge Plane for Autonomic Service Assurance of Network Services (e.g. 5G Network Slices); and Suppliers of Solutions for Dynamic Probing for Orchestrated Assurance within NFV/Clouds (Virtualized Environments) and the Integration/Convergence of Autonomic Service Assurance with Orchestrated Assurance for Newly Instantiated Network Services (VNFs and Service Chains). Further Planned Demos defined in White Paper No.1 [5] of this PoC will continue to consider the role and business models of Suppliers of GANA conformant Autonomic Management & Control Software (including ISVs and network vendors), suppliers of Network Elements (NEs) products, as well as innovators and suppliers of autonomics algorithms (powered by AI (Artificial Intelligence).

12. Conclusions

The Demo-1 and Demo-2 of ETSI 5G PoC produced a Report that describes the results and discussions outcome of the two Demos in terms of the Objectives described in this White Paper No.2 and in White Paper No.1 of this PoC and also the Network Operator's Requirements listed in the Problem Statement sections of this White Paper No.2 and White Paper No.1 of this PoC. Therefore, readers are encouraged to follow the developments, progression and the results (Demo Reports (e.g. Demo-2 Report) and more detailed material in form of Slides) of the ETSI 5G PoC that are accessible at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals [3], under AFI PoC web page, and there are plans for more demos as part of Demo series planned for the overall PoC in the timeframe 2018/2019 and beyond).

Demo-3 will focus on the following aspect:

- **Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring and Feeding of Knowledge into the GANA Knowledge Plane for Autonomic Service Assurance of 5G Network Slices; and Orchestrated Service Monitoring in NFV/Clouds**

13. References

[1] ETSI White Paper no. 16: The *Generic Autonomic Networking Architecture Reference Model for Autonomic Networking, Cognitive Networking and Self-Management of Networks and Services*: http://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp16_gana_Ed1_20161011.pdf

[2] ETSI TS 103 195-2 (published by ETSI in May 2018): 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***: https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=50970

[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: https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals

[4] Ranganai Chaparadza, Tayeb Ben Meriem, Dominik Spitz, David Ronen, Benoit Radier, Said Soulhi, Kostas Tsagkaris: ETSI 5G PoC on E2E Autonomic (Closed-Loop) Service Assurance of Network Slices through Cross-Domain Federation of GANA Knowledge Planes (KPs): submitted to the IEEE Magazine on Networking Standards 2018: https://www.comsoc.org/comstandardsmag/cfp/networking-standards

[5] 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: https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals

[6] ODA TM Forum's Open Digital Architecture (ODA): IG1167 ODA Functional Architecture Vision R18.0.0 (Intelligence Management Function Block)

[7] ETSI TR 103 473: Autonomicity and Self-Management in the Broadband Forum (BBF) Architectures: GANA Autonomics in BBF Architecture Scenarios

[8] ETSI TR 103 404: GANA instantiation onto the 3GPP Backhaul and Core Network architectures

[9] ONAP Open Source Project: ONAP Architecture Overview: https://www.onap.org/

[10] TIP Open Source Project: https://telecominfraproject.com/

[11] BBF CloudCO Open Source Project: https://www.broadband-forum.org/cloudco

[12] OPNFV Open Source Project: https://www.opnfv.org/

[13] ONOS Open Source Project: https://onosproject.org/

[14] OpenDayLight Open Source Project: https://www.opendaylight.org/

[15] ETSI OSM (Open Source MANO): https://osm.etsi.org/

[16] ACUMOS: An Open Source AI Machine Learning Platform: https://www.acumos.org/

[17] 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: https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals

[18] ODA TM Forum's Open Digital Architecture (ODA): IG1177 ODA Intelligence Management Implementation Guide: R18.5.0 (IG1177 Release 18.5, December 2018)

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ETSI World Class Standards

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Disclaimer: This White Paper expresses the opinion of the ETSI TC INT/AFI WG 5G PoC Consortium Steering Committee and the other contributors.

"This AFI Proof of Concept has been developed according to the ETSI NTECH AFI Proof of Concept Framework. AFI Proofs of Concept are intended to demonstrate AFI as a viable technology. Results are fed back to the Technical Committee on Network Technologies.

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