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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

ETSI PoC Demo-3 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.3
(of a series of White Papers expected from the ETSI PoC)

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ETSI TC INT AFI WG 5G POC

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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.2:*** ***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***

Executive Summary

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

To support Service Providers in their Digital Transformation strategy and assessment of pre-deployment of their digital business ecosystems for Network Slices, the ETSI 5G Slice PoC is running a series of Demos to demonstrate various aspects of relevance to 5G Network Slices Creation, Autonomic & Cognitive Management and Control (AMC) & E2E Orchestration; with Closed-Loop (Autonomic) Service Assurance for the IoT Slices (Smart Insurance) Use Case.
One of the key aspects being addressed by the PoC is the aspect of how to Build and Demonstrate the Telecom Operators' Desirable Framework for E2E Autonomic (Closed-Loop) Service Assurance of 5G Network Slices across 5G network domains such as Radio Access Network (RAN), Fronthaul; Backhaul, "Multi-Access Edge Computing" (MEC) sites and Core Networks.

ETSI TC INT/ AFI Working Group (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 real 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 the paper, to help readers understand the PoC's objectives.

Network Traffic Monitoring in 5G Network Slices needs to be implemented in a way that follows principles for Autonomic Management and Control (AMC) of Networks and Services prescribed by the ETSI GANA Framework—by which monitoring functions and mechanisms of the network are driven by a ***Framework for Autonomic Monitoring***.
Autonomic Monitoring involves the design and operation of autonomic monitoring components that intelligently orchestrate and dynamically program monitoring functions and mechanisms (e.g. components/tools) to meet the monitoring requirements of the network and its services, while the *autonomic monitoring manager components* implement analytics and cognitive algorithms that dynamically orchestrate or tune monitoring functions and mechanisms using control-loops. In GANA terms, these principles are described in the ETSI standard ETSI TS 103 195-2. The control-loops that should be driven by autonomic monitoring manager components are meant to continuously observe that monitoring objectives are being met and to continuously listen for new monitoring demands (e.g. in response to the instantiation of new 5G Network Slices or Services) or change requests, and react accordingly to ensure that "monitoring services" are meeting monitoring demands/objectives and that consumer entities that require to receive monitoring data from monitoring functions and mechanisms receive the monitoring data timely and effectively. In that regard, some of the key aspects that network Operators for 5G are requiring to be addressed by Vendors (Solution Suppliers) of network traffic monitoring solutions are: ***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 (i.e. Virtualized Network Environments).

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 complements other White Papers that are based on Demo-1, 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 being addressed by Demo-3 of the ETSI TC INT/AFI 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) 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 components" themselves (which must be viewed as Software Logic/ Algorithms and could be implementable as standalone processes (e.g. as *microservices*) or having some combined together to run/execute as a single process at run-time.

Moreover, Digital Service Providers seek to view Autonomic Decision-making Element logic (modular "autonomic manager components") as Run-Time (re)-Loadable / replaceable SW (Software) 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 components that exhibit better algorithms 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.

The third industry consensus this Demo-3 objective tries to achieve - as part of the whole Service Assurance lifecycle of Network Slices- and as complemented by the two previous consensuses, is the need for "Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring". This is an approach to monitoring which provides for a high degree of flexibility in dynamic programming within the traffic flows monitoring space and reduces dramatically the cost of monitoring solutions compared to current static monitoring which is not applicable in the context of 5G Network Slices and Self-Managed (autonomic) networks.

Another important aspect for consideration at this juncture in 5G developments is the need to intensify efforts in looking into the development of a rich standardized model/framework (as a template) that can be used by Service Providers for QoS (Quality of Service) Classes definitions and their mappings to SLAs (Service Level Agreements) definitions for E2E Slices so as to feed those definitions as inputs to GANA Knowledge Planes for the Federated E2E Autonomic Service Assurance of Slices (and the flow-level services they carry) across network segments/domains.

In the broader scheme of desirable traffic monitoring services for 5G Slices, monitoring functions and mechanisms in 5G networks need to be implemented according to dataflow computing models, which have been studied for decades as a mainstream approach of performance, scalability and timeliness in parallel distributed systems. Dataflow computing models are now becoming a mainstream approach of event stream processing and distributed monitoring in presence of large amount of data, with real-time constraints. This monitoring trend appeared with the evolution of big data platforms to support event stream processing and fast data services, and it appears that some 5G network slices can be viewed as consisting of really big and fast data streams systems, which need to be monitored according to the principles of fast data stream processing platforms (Spark Streaming, Google Dataflow, Apache Flink & Beans, etc.).
This approach of employing dataflow computing models and dataflow-based distributed stream processing in traffic monitoring is described in [6].

Network user traffic and control traffic monitoring in 5G slices, according to the traffic monitoring principles desired for autonomic management and control of networks and services (including slices), can also be implemented as distributed dataflow systems [6]. It is expected that from now and into the near future, Traffic Monitoring Fabrics that form Out-Of-Band (OOB) Traffic Aggregation Network that is SDN (Software-Defined Networking) programmable, Network Functions such as VNFs (Virtualized Network Functions), and also Dynamic Probing infrastructures, will all need to support the execution of dataflow-based distributed stream processing platforms for monitoring operations required to create Telemetry Data Lakes and to feed Autonomic Functions (i.e. GANA Decision Elements (DEs) components) with monitoring data or synthesized knowledge they require to drive their associated control-loops.
This approach is being experimented for 5G RAN segments built with cloud-RAN nodes to support the execution of vBBU (virtualized BaseBand Units) VNFs. The same approach could be adopted for traffic monitoring in other production network segments (e.g. X-Haul, virtualized core networks, edge clouds or Telco-Cloud in general), but with slightly different objectives in terms of data capture and dissemination requirements, monitoring operations that should be performed for each slice, delays constraints or other quality of service delivery objectives that should be met by the network segment.
The dataflow-based distributed stream processing approach is also applicable in OOB Traffic Monitoring Aggregation Networks that 5G Network Operators should deploy.

For example, for the 5G RAN segment what can be emphasized is the collection of information such as the quality of signals between end users and cells (the channel quality indicators, or CQI) and the monitoring of the performance of vBBU functions, monitoring operations performed within a very small time scale (e.g. typically within a few dozens of milliseconds) for the distributed control of RAN operations).
For the mobile core, it may be more important to monitor some traffic patterns between access nodes and the core (EPC or 5GC), or to monitor the availability or reliability behavior of the virtualized version of EPC (Evolved Packet Core) functions (P-GW, MME, HSS, etc.), and these kinds of monitoring operations are more likely to take place at a higher time scale (about a few second to minutes or hours).
Concerning implementations, what is desirable is to use cloud-native services in place of traditional VM-based cloud services, particularly in the case of the need to deploy monitoring components (especially agents, probes) within a shorter time scale, and when it becomes needed to scale up (and down) computing resources required by VNFs in a very short time scale, e.g. within hundreds of milliseconds or a few seconds. As such, in the NFV based environments "*cloud-nativeness*" is a desirable attribute to monitoring services (monitoring services as VNFs, provided as cloud services, built as stream processing components, to enable the monitoring of 5G network services instantiated in a virtualized environment with fast data analysis.

1.2. Background of the ETSI TC INT/AFI WG 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 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 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 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 Problems and Challenges being addressed and clarified in the PoC

One of the ***Requirements*** for the Service Provider to be able to implement the desirable *Framework for E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices* is the ***Deployment of Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring and Feeding of Knowledge into the GANA KPs for E2E Autonomic Service Assurance of 5G Network Slices***. At the same time, such Programmable Traffic Monitoring Fabrics should be designed and deployed as part of the ***Telecom Operator's Desirable Framework for Dynamic Probing for Orchestrated Assurance and the Integration/Convergence of Autonomic Service Assurance with the Orchestrated Assurance of Newly Instantiated Network Services such as Virtual Network Functions(VNFs), 5G Network Slices and Service Chains, as part of the larger Framework for E2E Autonomic (Closed-Loop) Service Assurance.***

The Network Operators' **Key Requirements** that belong to the Problem Statement that underpins the Demo-3 of the ETSI 5G PoC derive from the following enablers and questions pertaining to the desirable Programmable Traffic Monitoring Solutions for 5G Network Slices:

- *The role, logic and required intelligence of the GANA KP-level Monitoring DE (Decision Element) in the GANA Knowledge Plane in driving the Programming of Traffic Monitoring Fabrics (dynamic configuration of traffic monitoring services) through "SDN Controllers" specially designed for Programming Traffic Monitoring Fabrics*
- *Policy Control of Monitoring behaviors of Managed Entities(MEs) in NEs (Network Elements) w.r.t Traffic Monitoring and export of Traffic Traces to Storage Devices (Data Collectors) or to out-of-band TAP and SPAN Aggregation Networks by NEs. TAP stands for Test Access Point and SPAN stands for Port Mirroring on switches*
- *Policy control of monitoring behavior and the TAP & SPAN Aggregation network to enable timely (real-time or near real-time) decision making by monitoring data (or knowledge) consumers in the Knowledge Plane (e.g. the QoS Management-DE for autonomic(closed-loop) QoS Management of Network Slices within a particular network segment). The interactions of a Knowledge Plane Monitoring-DE and a Knowledge Plane QoS Management-DE*
- *SDN based Control of Traffic Streams in the Monitoring Fabrics: merging, traffic replication and forwarding to the Tools, and the application of advanced features in traffic capturing, source tagging for captured packets, slicing, Header-Stripping, etc., and dataflow-based distributed stream processing aspects*
- *Data Storage (Collectors) and Analytics Algorithms for Knowledge Derivation, and Scaling Data Collectors (e.g. Traffic Storage) based on Network Workloads Requirements*
- *Filtering of Data on Data Collectors and Dissemination to the GANA Knowledge Plane(s) and any other Tools that need the Traffic Data or knowledge synthesized from raw data on the collectors*

- *Knowledge Representation, Presentation and Feeding into the GANA KP DEs and ONIX by Cognitive Algorithms running on Data Collectors*
- *Interworking and Coordination of Monitoring DEs in the case of Federated GANA KPs for the Access (RAN), X-Haul Transport Network and Core Network*
- *Understanding Cost-Effective and Scalable Solutions for TAP and SPAN Aggregation Networks as Programmable Monitoring Fabrics and Distributed Nature of Programmable Monitoring Fabrics*
- *Performance and scalability of the Network Level Monitoring DE (the monitoring DE with its complex analytics)*
- *SLAs Violation Detection by the Monitoring DE in collaboration with Automated Test System or Components*
- *Monitoring DE interface with Orchestrators for the need to trigger Orchestrated Assurance*
- *Orchestration and dynamic configuration of Traffic Monitoring Agents (Virtual Taps, Virtual Probes) in the Virtualized Environments (particularly the Telco-Cloud/NFV Environment) in response to service creation (i.e. Virtual Network Function (VNF) or a whole service chain, and dataflow-based distributed stream processing aspects*
- *Agility of scale-up/scale-down monitoring agents and monitoring DE (scaling it with monitoring requirements/workloads) with cloud-native Telco-Cloud solutions and container-based virtualization*
- *The Interplay of Programmable Monitoring and Dynamic Probing with Service Fulfilment upon the completion of Network Slice Creation process, including the extent to which "slice awareness" is needed in monitoring requests and in the monitoring services themselves*
- *Slice KPIs (Key Performance Indicators) and interplay with the GANA Monitoring-DE in Knowledge Plane as orchestrator of monitoring functions(services)*
- *Network Links Density expected in 5G Fronthaul, Midhaul, Backhaul and Core Networks*
- *Consideration of dynamic resource management within a QoS framework built upon a 5G network slicing architecture to deduce the auto-tuning behavior expected on slice monitoring services*
- *Consideration of provisioning of end-to-end slices and behavioral modelling of services (including flow-level services, e.g. IP Flows) in a dynamic environment including resource allocation per slice, preemption and reprioritizing, resource adaptation per slice for maximal fairness, throughput, or SLA compliance, to deduce the impact of such dynamics on slice monitoring solutions*
- *Consideration of Autonomic Service assurance and SLA compliance of services based on their profiles and overall resource availability in the holistic network (end-to-end) in the shared resource pool, to deduce the impact on slice monitoring solutions*
- *The way QoS Classes and SLA definitions for E2E Slices are fed as inputs to the GANA Knowledge Plane for Autonomic Service Assurance of the Slices and possibly the need for a Standardizing a rich Model (as Template) that can be used by Service Providers for QoS Classes and SLA definitions for E2E Slices.*

1.4. How the White Paper is organized

In order to understand the concepts and network operators' requirements being addressed by this Demo-3 (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 AMC for networks and services (including the concept of autonomic service assurance). The paper also presents the value of Multi-Layer Autonomics and the integration of the GANA KP with Orchestrators, SDN Controllers, and OSS/BSS systems (Operations Support System/Business Support System). The paper then summaries the Objectives targeted by the Demo-3 and presents the ***Capabilities of Big Switch Networks*** (a vendor/supplier of network traffic monitoring solutions that match very well the era of *Network Software'rization, SDN/NF and 5G*). ***Big Switch Networks*** capabilities do address some of the outlined Telecom Operators' Requirements on *Traffic Monitoring as enabler for E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices*, which has to include *Dynamic Probing for Orchestrated Assurance and the Integration/Convergence of Autonomic Service Assurance with the Orchestrated Assurance of Newly Instantiated Network Services such as Virtual Network Functions(VNFs), 5G Network Slices and Service Chains*. The White Paper then looks into Vendors' (suppliers') Business View of the Overall 5G PoC, more background details on the ETSI 5G PoC, ETSI-GANA Model as key Enabler for 5G, and the value of Federation of GANA KPs for E2E Autonomic (Closed-Loop) Service Assurance across the various network segments/domains.

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

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 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 domain (scope of management aspects/problems)" such that it can run as a "micro service". Examples of autonomic manager elements (i.e. 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*. DE components of the GANA KP are "macro" autonomic managers (atomic and modular) that drive logically centralized network-wide with slow control loops that operate in "slower timescale" than similar control-loops introduced to run in Network Elements (NEs) and operating as "fast control-loops". 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:

- **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.

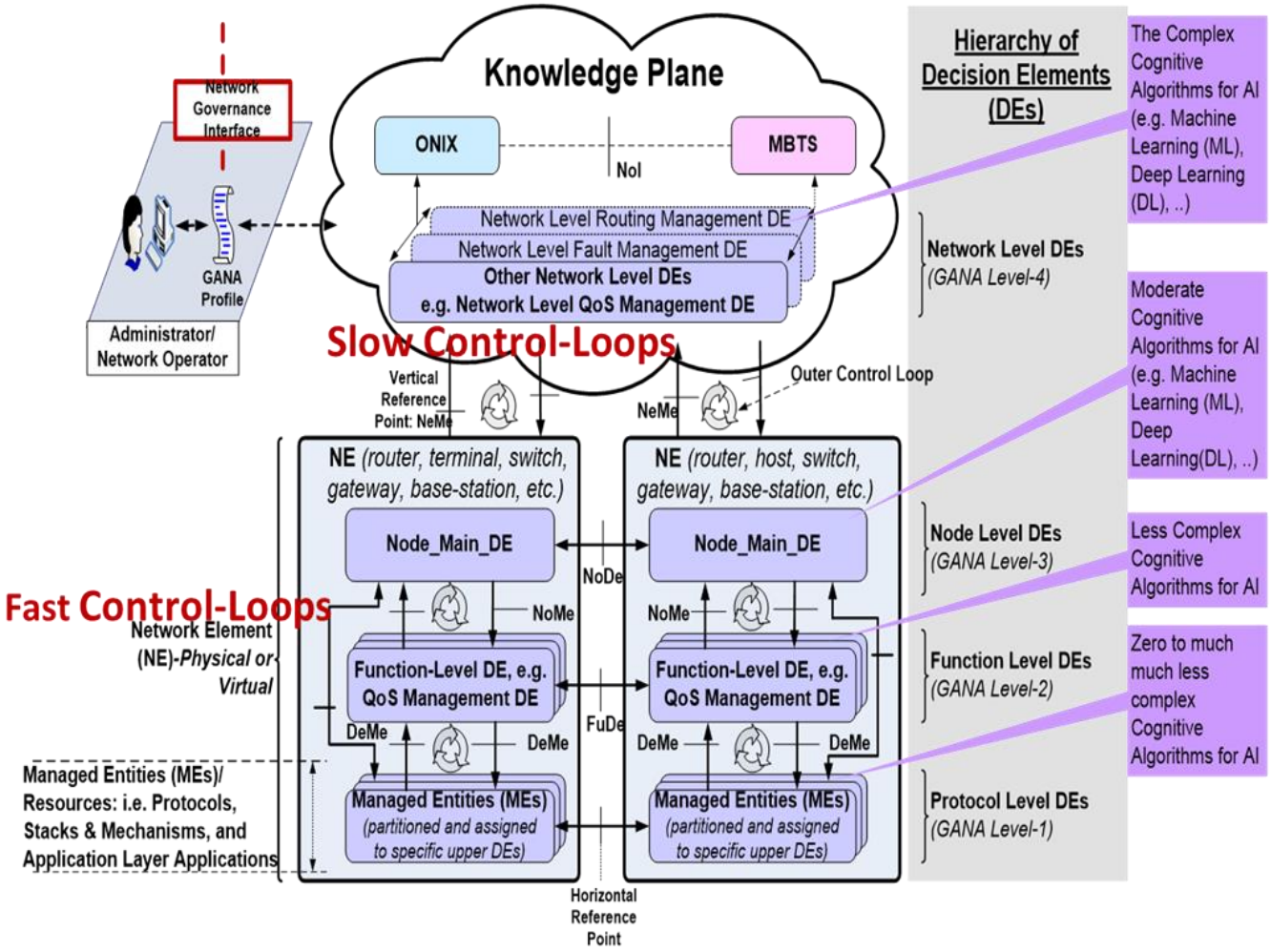


Figure 1: ***Snapshot of the GANA Reference Model and Autonomics Cognitive Algorithms for Artificial Intelligence (AI)***

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 logics, 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 Algorithms) cannot be standardized and 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), and 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 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***, 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 a NE and some may require the coordination/synchronization of "all" the DEs. The figure below (Figure 2) illustrates this aspect of the need for Collaboration/Coordination of DEs. This subject is linked to the topic of addressing stability of control-loops and 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.

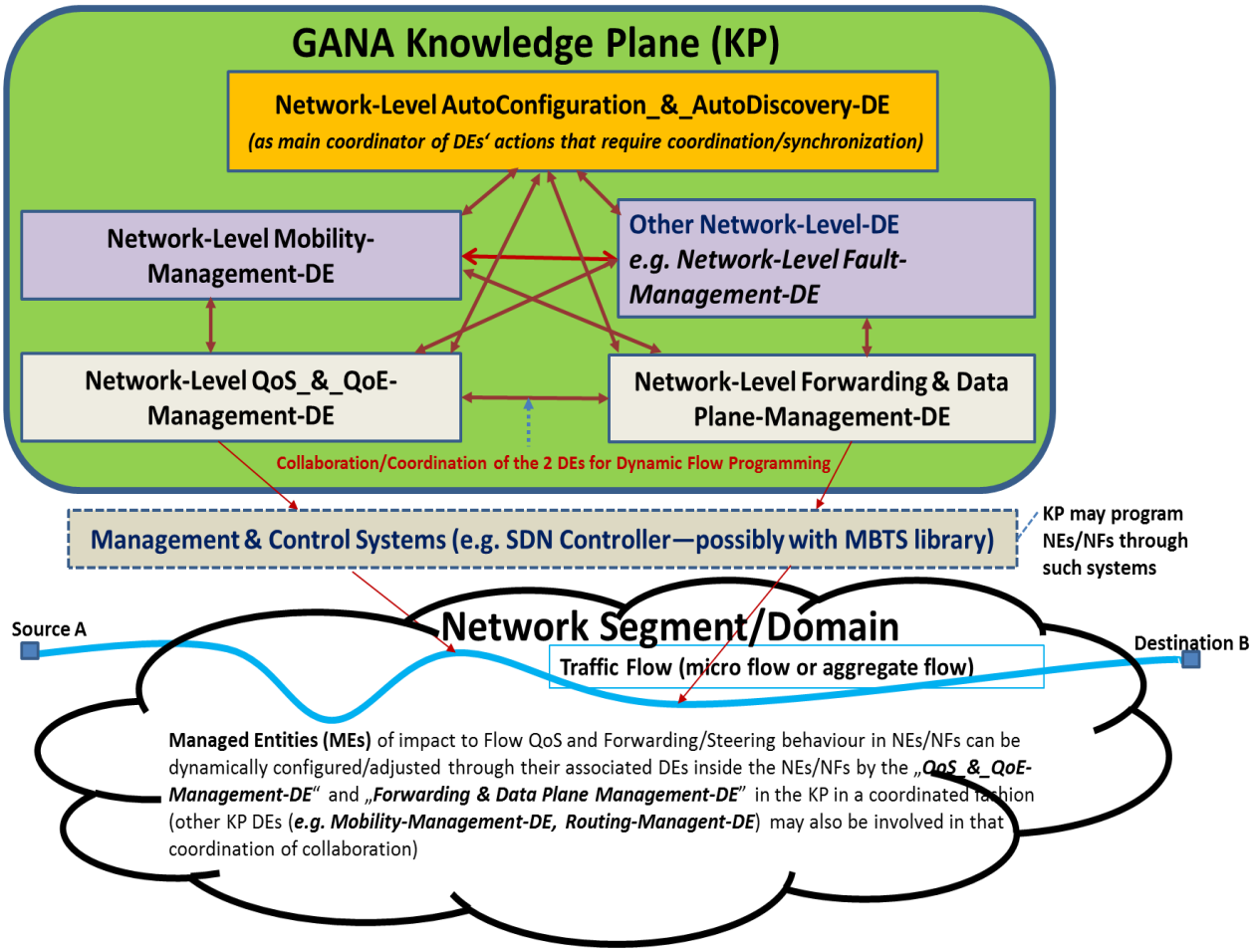


Figure 2: Need for collaboration or coordination of Autonomic Functions (DEs) on certain actions or aspects that are better addressed through collaboration/coordination

5. Multi-Layer Autonomics and the integration of the GANA Knowledge Plane (KP) with other systems, e.g. with Orchestrators, SDN Controllers, and OSS/BSS or Configuration Management Systems

Autonomics (control-loops) can be introduced at various layers of management and control operations as illustrated in this section and the associated figures. 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 KP platform vendor), may have a wider scope 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.

The diagrams below (see Figures 3 and 4) 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 (Decision Elements (DEs)) can be implemented (as illustrated on Figure-1, regarding the ETSI GANA Model).

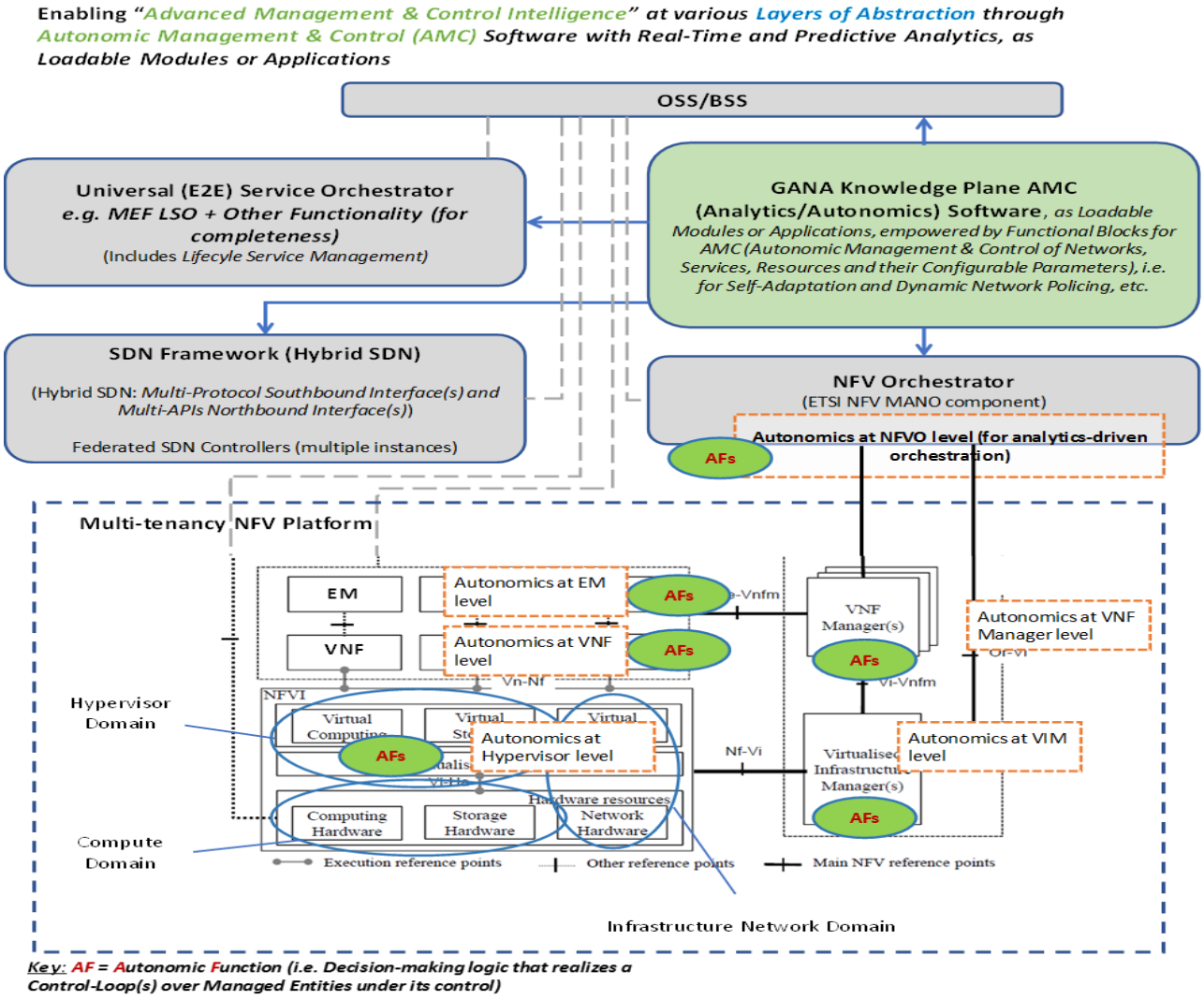


Figure 3: ***Multi-Layer Autonomics and the integration of the GANA Knowledge Plane with Orchestrators, SDN Controllers, and OSS/BSS systems and/or Configuration Management Systems***

Figure 4 presents a GANA Knowledge Plane that has 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. As illustrated, 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.

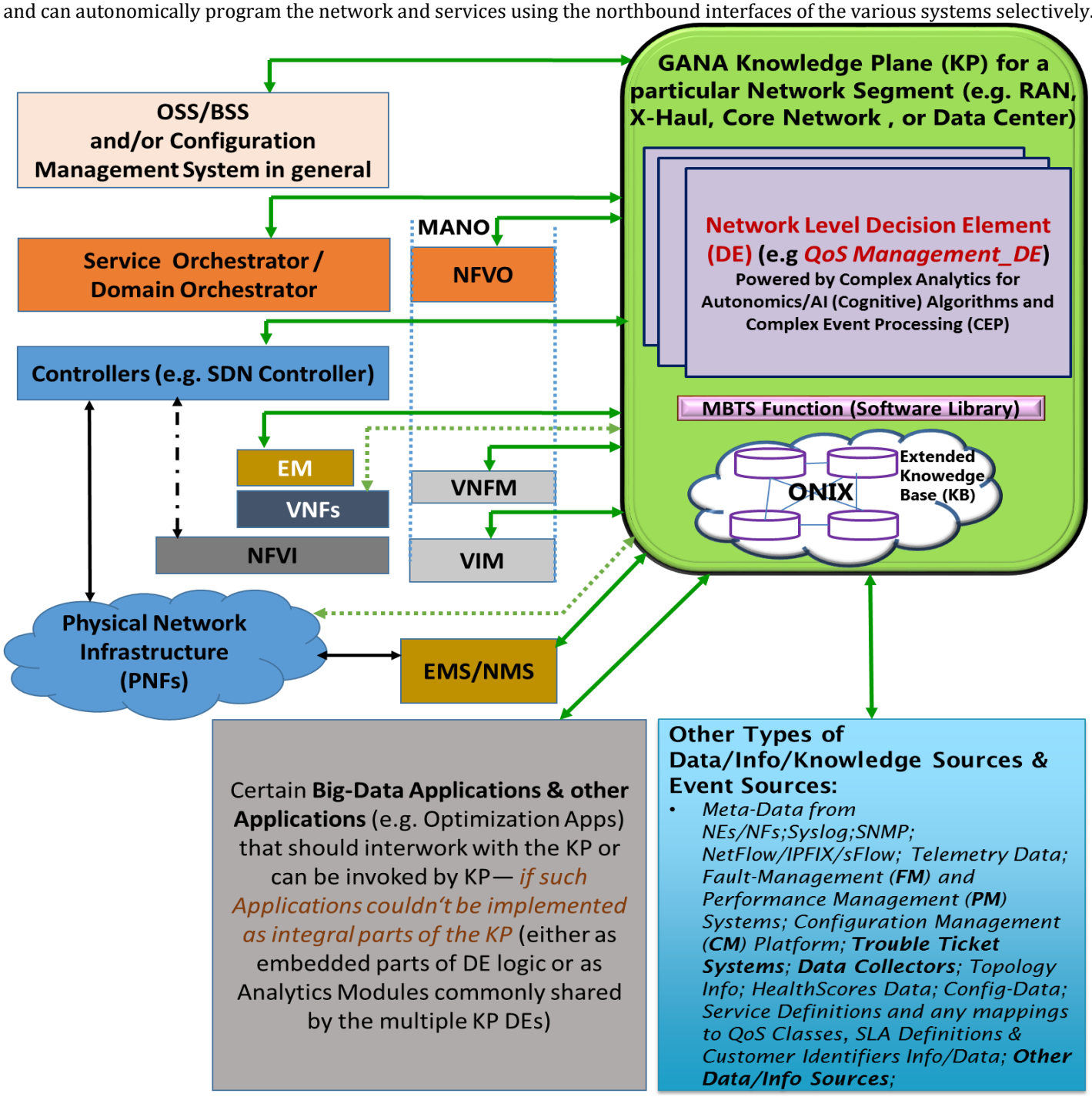


Figure 4: ***Big Picture on possibilities w.r.t KP's data sources diversity, events visibility and consumption into KP DE algorithms and decision-making processes, as well as KP integration with a variety of management and control systems for certain KP Implementation scenarios***

GANA Knowledge Plane is to be considered as 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 and VNFs 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 of the systems' 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 Figures 5 and 7, 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 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. The Objectives being addressed by Demo-3 of the ETSI PoC

6.1. Overview

The following diagrams illustrate key components that may all be involved in playing a role in delivering Autonomic (Closed-Loop) Service Assurance of 5G Network Slices:

- *GANA Knowledge Plane for a specific network segment(s);*
- *SDN-Driven Programmable Traffic Monitoring Fabrics;*
- *Network Elements (PNFs/VNFs);*
- *Traffic Monitoring Probes;*
- *Data Collectors;*
- *NMs/EMs (Network Managers/Element Managers);*
- *PMs (Performance Managers);*
- *FMs (Fault-Managers);*

- *Automated Test System for Orchestrated Assurance and SLA Violations Detection;*
- *SDN Controller Framework for the production network;*
- *OSS;*
- *Configuration Management Tools that complement an OSS that may be in place or are deployed to play a role that in some cases is simply played by an OSS platform that covers the full spectrum of FCAPS functions*
- *Service and Domain Orchestrator systems.*

The Diagram below (Figure 5) is a general picture, while the diagrams (derived from the general picture presented in Figure-5) that follow after define the Scope of focus for Demo-3. NOTE: In terms of diversity of data and event sources of a GANA Knowledge Plane (KP) implementation and also the 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, a Telco Cloud environment and its NFV environment (including associated MANO stack) should also be considered in integration with a KP as illustrated in Figure 5.

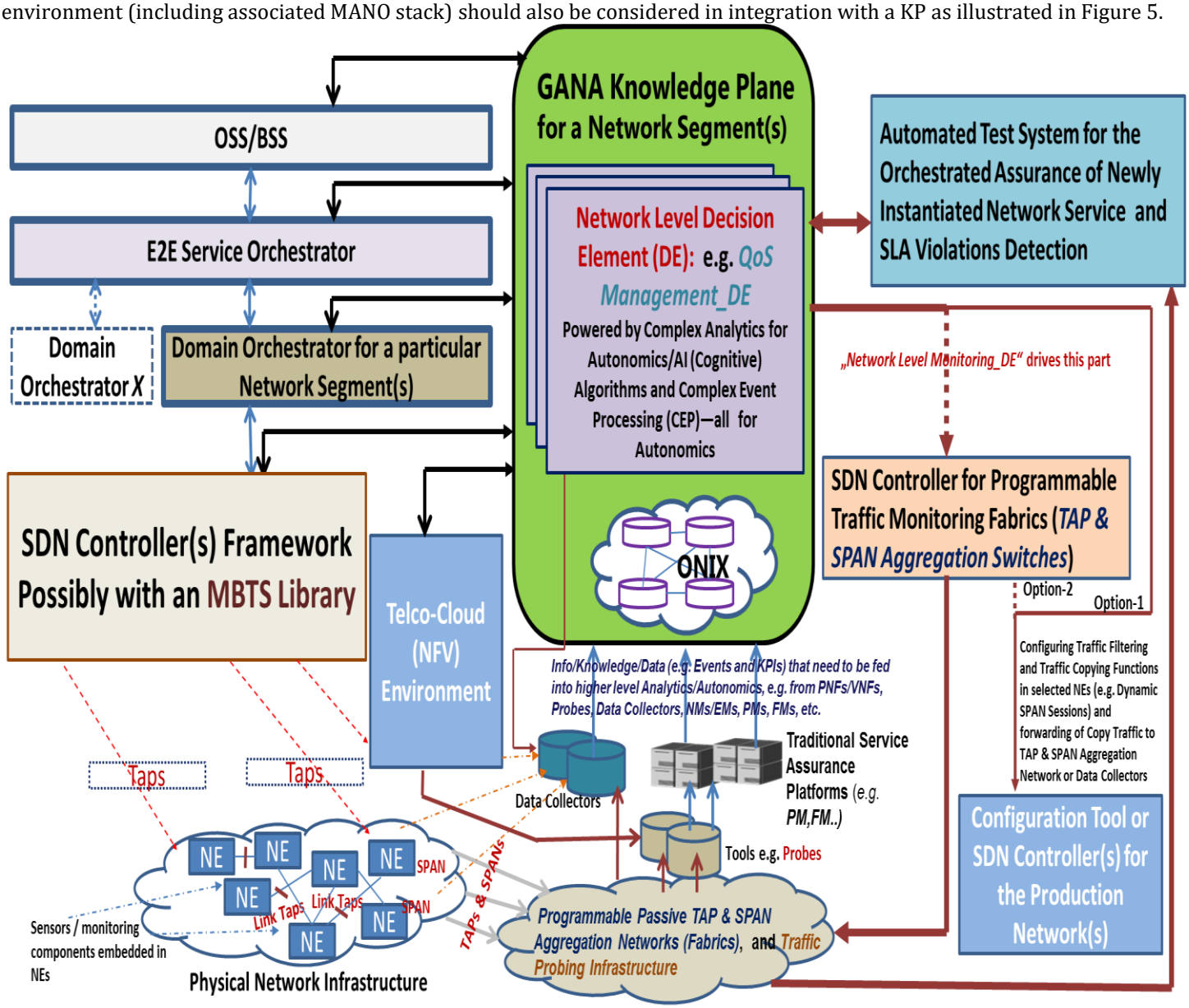


Figure 5: *Generic High-Level Picture on Key Components for Autonomic Service Assurance for Network Services (e.g. 5G Network Slices), Components' interactions and Data Sources (including Event Sources)*

6.2. Objective-1

Objective-1 of Demo-3 (see Figure-6): This objective focuses on demonstrating the roles that should be played by Monitoring Data Collectors and Programmable Traffic Monitoring Fabrics in Knowledge Representation and Presentation to the GANA Knowledge Plane (in reference to the RAT (Representation, Acquisition and Translation) Function for Knowledge feed into Knowledge Plane—described in GANA TS (ETSI TS 103 195-2). Figure 6 illustrates the scope of this Objective-1. **NOTE:** In reference to the integration of the GANA Knowledge Plane with Big-Data Applications for AMC as shown on Figure 6 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).

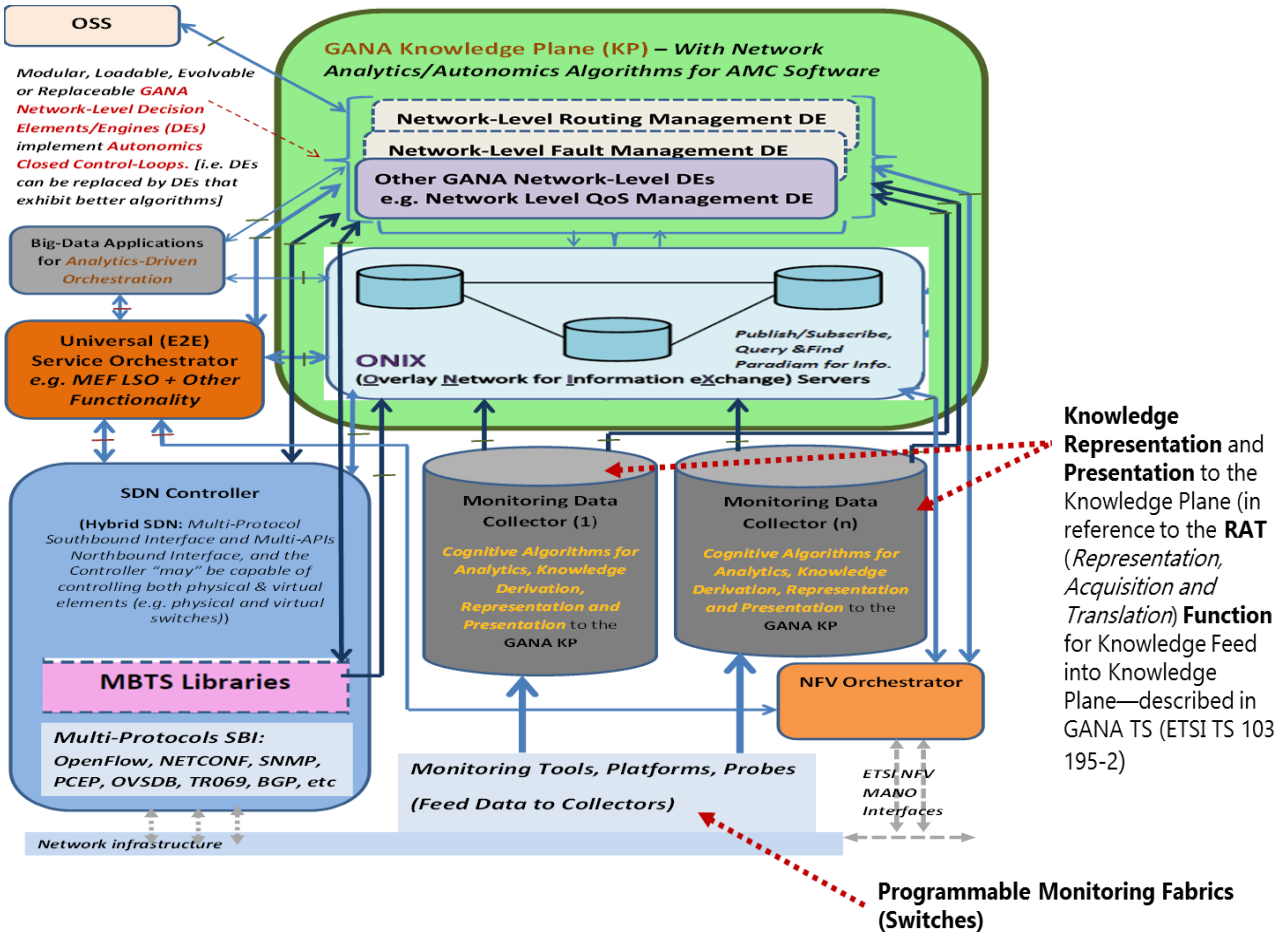


Figure 6: *The roles played by Monitoring Data Collectors and Programmable Traffic Monitoring Fabrics in Knowledge Representation and Presentation to the GANA Knowledge Plane*

6.3. Objective-2

Objective-2 of Demo-3 (see Figure-7): This objective focuses on demonstrating the roles that should be played by the following components in autonomic service assurance of 5G Slices:

- *Monitoring Decision Element (DE) in the GANA Knowledge Plane,*
- *SDN Controller for Programmable Traffic Monitoring Fabrics (TAP & SPAN Aggregation Switches),*
- *Programmable Passive TAP & SPAN Aggregation Networks (Fabrics),*
- *Automated Test System for Orchestrated Assurance and SLA Violations Detection,*
- *Configuration Tool or SDN Controller(s) for the Production Network(s).*

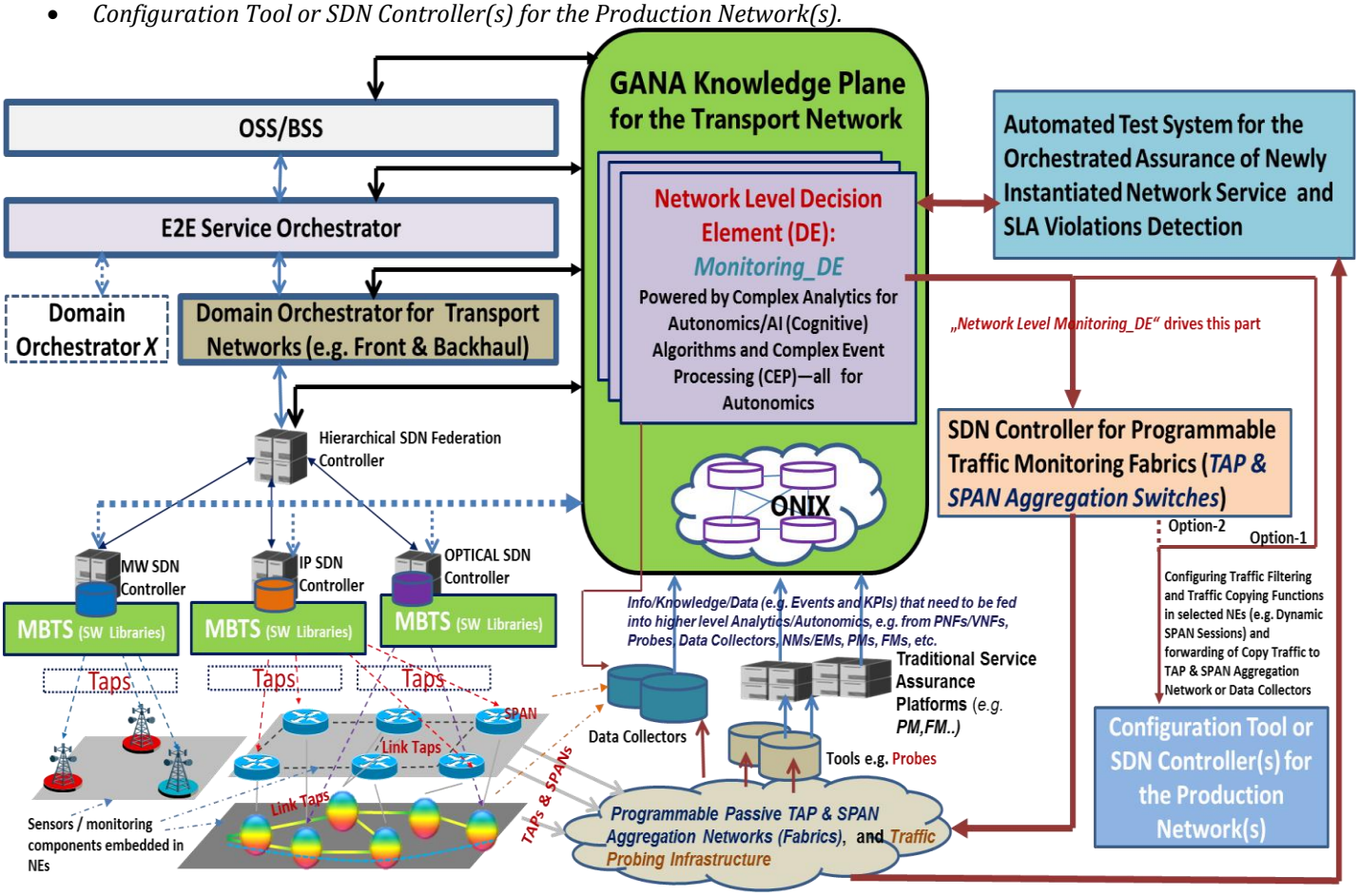


Figure 7: *The roles played by the Monitoring Decision Element (DE) in the GANA Knowledge Plane, SDN Controller for Programmable Traffic Monitoring Fabrics, Programmable Passive TAP & SPAN Aggregation Networks (Fabrics), Automated Test System for Orchestrated Assurance and SLA Violations Detection, and Configuration Tool or SDN Controller(s) for the Production Network(s)*

NOTE: According to the ETSI GANA model, as described in ETSI TS 103 195-2, ***Autonomic Monitoring*** *behaviors* (defined earlier) for a Network Element/Function (NE/NF) and for the overall network are to be realized by a *Monitoring DE* implemented in a NE/NF and by the global *Network Level Monitoring DE* implemented in the GANA Knowledge Plane realm, respectively, including the interworking of the Monitoring DEs vertically and across multiple network segments and their associated GANA Knowledge Planes.

Figure **8** provides insights on a distributed framework for the integration of autonomic service assurance and orchestrated assurance, with indications of the components of focus in Demo-3 of the ETSI 5G PoC and interfaces (e.g. APIs (Application Programming Interfaces)) of main focus in Demo-3.

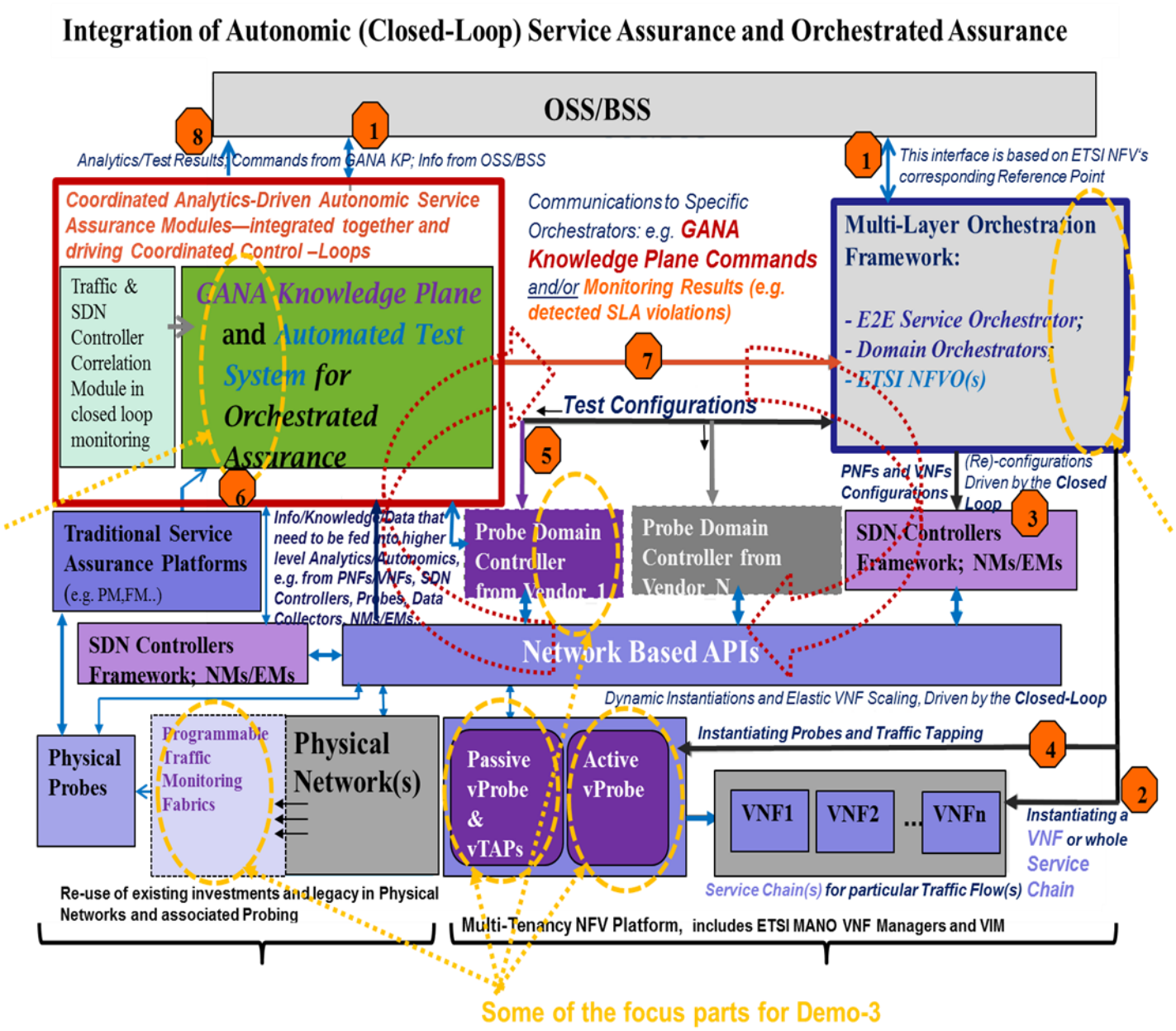


Figure 8: *The Integration of Programmable Traffic Monitoring Fabrics (TAP & SPAN Aggregation Switches) within the broader picture of Telecom Operator's Desired Framework for Dynamic Probing for Orchestrated Assurance and the Integration/Convergence of Autonomic Service Assurance with Orchestrated Assurance for Newly Instantiated Network Services*

The following table summarizes the interactions on the interfaces to illustrate the Integration of Dynamic Probing for Orchestrated Assurance and the Integration/Convergence of Autonomic Service Assurance with Orchestrated Assurance for Newly Instantiated Network Services.

Interface/Interaction Sequence	Interaction Description
1	• Configuration of the GANA Knowledge Plane Components (e.g. DEs) and inputs flow from the OSS/BSS to the Knowledge Plane • Triggers and inputs from the OSS/BSS on orchestration of a new service (e.g. a VNF or a service chain) in response to 5G Network Slice Creation demands (for example)
2	• Instantiating a Network Service (e.g. a VNF) and/or a Service Chain (chained VNFs)
3	• PNFs and VNFs Configurations and connectivity configurations by Orchestrators through SDN controller(s) as required
4	• Instantiating Probes (virtual Passive and Active Probes) and Traffic Tapping (virtual Taps) in response to triggers from Probe Domain Controllers
5	• Test Configurations for instantiated virtual probes (vProbes) and virtual taps (vTaps) are issued by an Orchestrator via a Probe domain controller, after the Probe domain controller has triggered the Orchestrator (e.g. NFVO) to instantiate (orchestrate) the Agents (vProbes and vTaps) in the Virtualization host (NFV Platform)
6	• Info/Knowledge/Data that need to be fed into higher level Analytics/Autonomics in the GANA Knowledge Plane, e.g. from PNFs/VNFs, SDN Controllers, Probes, Data Collectors, NMs/EMS, and other relevant data sources • Test/Measurement results from Probes and Probe domain controllers to the Automated Test System and to GANA Knowledge Plane DEs (e.g. to the Monitoring DE and other DEs such as the Auto-Configuration DE) that may need to use the test results
7	• The GANA Knowledge Plane (e.g. through the Auto-Configuration-DE in collaboration with other KP DEs such as Resilience & Survivability-DE, Fault-Management-DE) may exercise analytics-driven service orchestration as a way to create a backup service that offers redundancy to a service in place that may need to be terminated after failover to the newly created backup service, and this can be done by the Knowledge Plane sending commands to specific Orchestrators (if not via the OSS as the system through which to trigger the service instantiation operation). • Test system obtains Monitoring Results (e.g. detected SLA violations) from probes and probe domain controllers to determine the extent of SLA violation for the service under test, and may be configured to send the results to the Orchestration Framework so that a re-orchestration could be performed or a resource scale up operation can be performed by an orchestrator to improve the performance of the newly instantiated service or service chain. The Test system may also send the test results into the OSS/BSS system
8	• Analytics results from the GANA Knowledge Plane Monitoring DE or Test Results from the Test System may be communicated to the OSS/BSS system • Commands may be issued by GANA KP DEs (e.g. the Auto-Configuration-DE in collaboration with other KP DEs such as Resilience & Survivability-DE, Fault-Management-DE) to the OSS, as a result of KP analytics results concerning the performance and reliability of a particular service that determine (by way of the KP

	DE algorithms) that a new service instance should be created through the OSS as part of service remediation strategies exercised by the Knowledge Plane.

NOTE: The Test System may use monitoring data from the probes and possibly packets data from the monitoring fabric as well in test case executions and verdicts passing.

Other aspects of consideration regarding the interfacing and interactions between the GANA Knowledge Plane and a Test System for use during orchestrated assurance of services are as follows:

- **Interactions between the Monitoring-DE in the GANA Knowledge Plane and the Test System**: —The GANA Knowledge Plane Monitoring-DE receives from the Test System the Test results for a newly created service and then correlates the results with other data from other monitoring points in the overall network to determine whether SLA for the particular service is being violated and whether monitoring services need to be dynamically adjusted accordingly. The Monitoring-DE can configure monitoring services of some components through the Probe Domain Controllers

- **Interactions between the Auto-Configuration-DE in the GANA Knowledge Plane and the Test System**: The GANA Knowledge Plane Auto-Configuration-DE, on-behalf of all the KP DEs, can trigger the Test System to execute tests on newly instantiated service or repaired service as a result of service assurance oriented analytics performed by the Knowledge Plane on the currently running services.

6.4. Objective-3

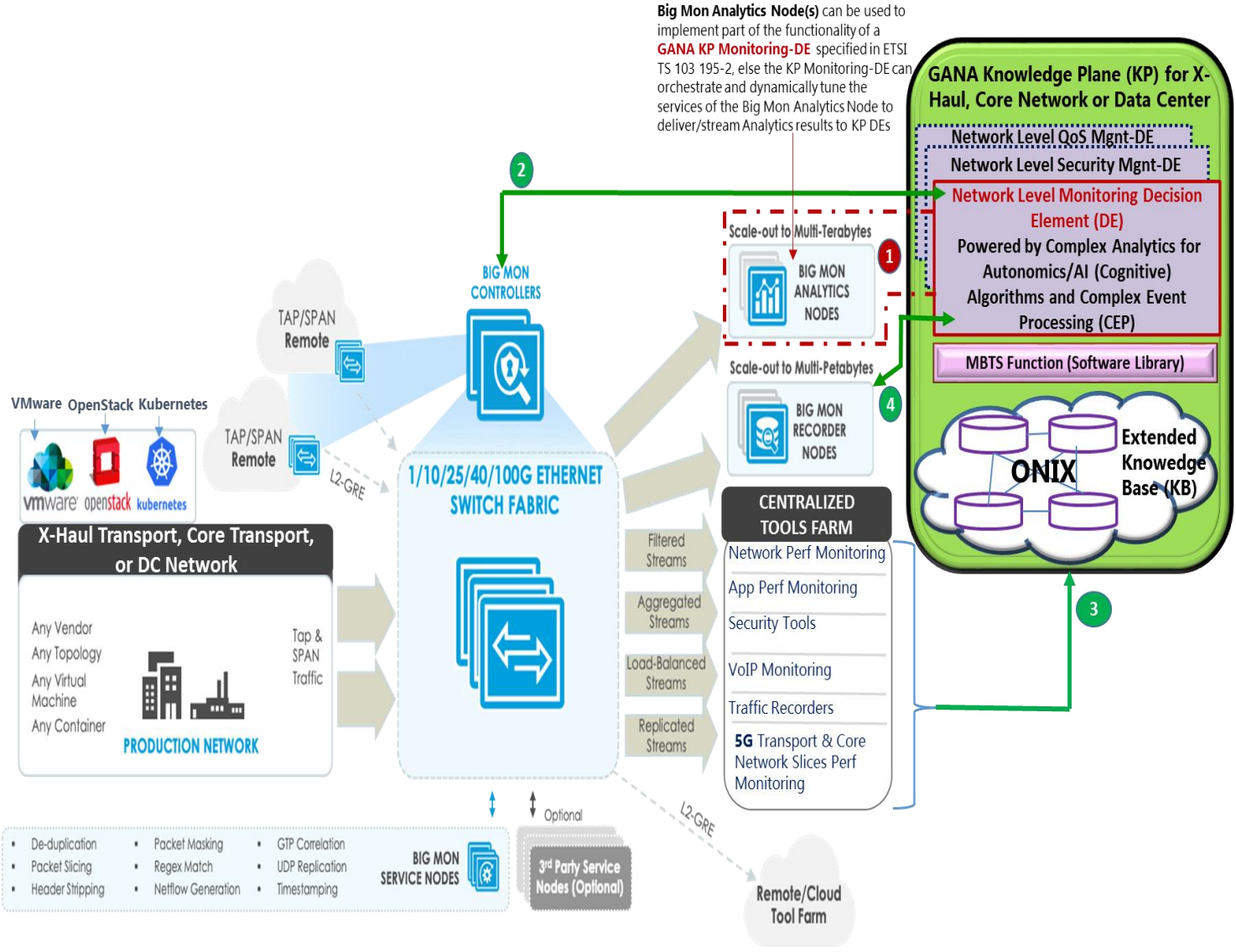
Objective-3 of Demo-3(see Figure-8): This objective focuses on demonstrating the Integration of *Programmable Traffic Monitoring Fabrics (TAP & SPAN Aggregation Switches)* within the broader picture of the *Telecom Operator's Desired Framework for Dynamic Probing for Orchestrated Assurance and the Integration/Convergence of Autonomic Service Assurance with Orchestrated Assurance for Newly Instantiated Network Services (e.g. 5G Network Slices and Service Chains).* This objective also considers the subject of the provisioning of end-to-end 5G slices and behavioral modelling of services in a dynamic environment involving resource allocation per slice, preemption and reprioritizing slices, resource adaptation per slice for maximal fairness, throughput, or SLA compliance, so as to deduce the impact of such dynamics on slice monitoring solutions. This also implies looking into the way QoS Classes and associated SLA definitions for E2E Slices are fed as inputs to the Federated GANA Knowledge Planes for Autonomic Service Assurance of the Slices (and the flow-level services they carry, e.g. IP Flows), while taking into consideration dynamic resource management within a QoS framework built upon a 5G network slicing architecture that is presented later in section 12 of the White Paper. **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.

6.5. Objective-4

Objective-4 of Demo-3(see Figure-8): This objective focuses on demonstrating *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); and dataflow-based distributed stream processing aspects.*

7. 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

The following diagram (Figure 9) illustrates some of the traffic monitoring capabilities of Big Switch Networks [5] that are applicable to this ETSI 5G PoC Demo-3. Later in this section a mapping of the various Big Switch Networks' capabilities that are applicable to this 5G PoC, to the GANA Framework, are described.



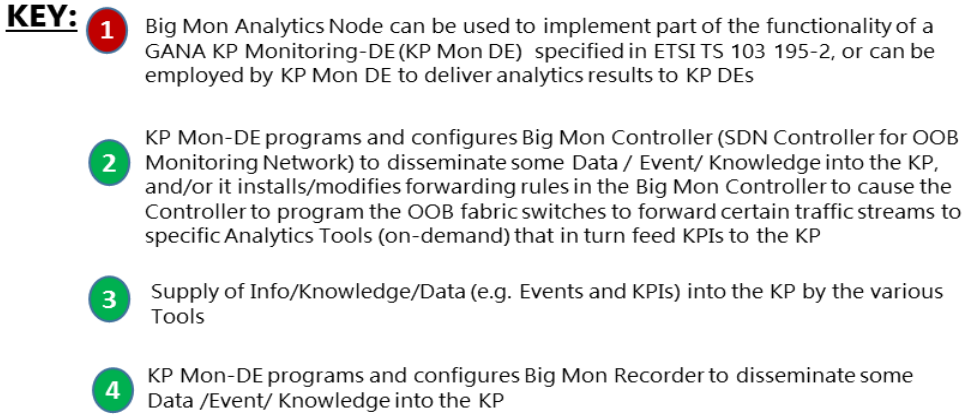


Figure 9: *The Big Switch's SDN Programmable Traffic Monitoring Fabric (TAP & SPAN Aggregation Switches) and integration with Centralized Tools Farm (Traffic Analyzers) and Packet Recorders (Collectors) that can generate "knowledge" from raw traffic and feed it into the GANA Knowledge Planes*

NOTE: As noted in Figure 9, the *Big Mon Analytics Node(s),* in playing the role of a Monitoring DE of the GANA Knowledge Plane, can potentially be extended to implement a full-fledged *GANA Knowledge Plane Monitoring DE* that fulfills the functionality specified in ETSI TS 103 195-2.

As illustrated in Figure 10 below, Big Switch Networks' Capabilities include Controller capability for integrated *In-Line Monitoring* and *Out-of-Band Monitoring*, and such a capability can play a role in security monitoring (an aspect that is also relevant for consideration of 5G Network Slice security monitoring aspects).

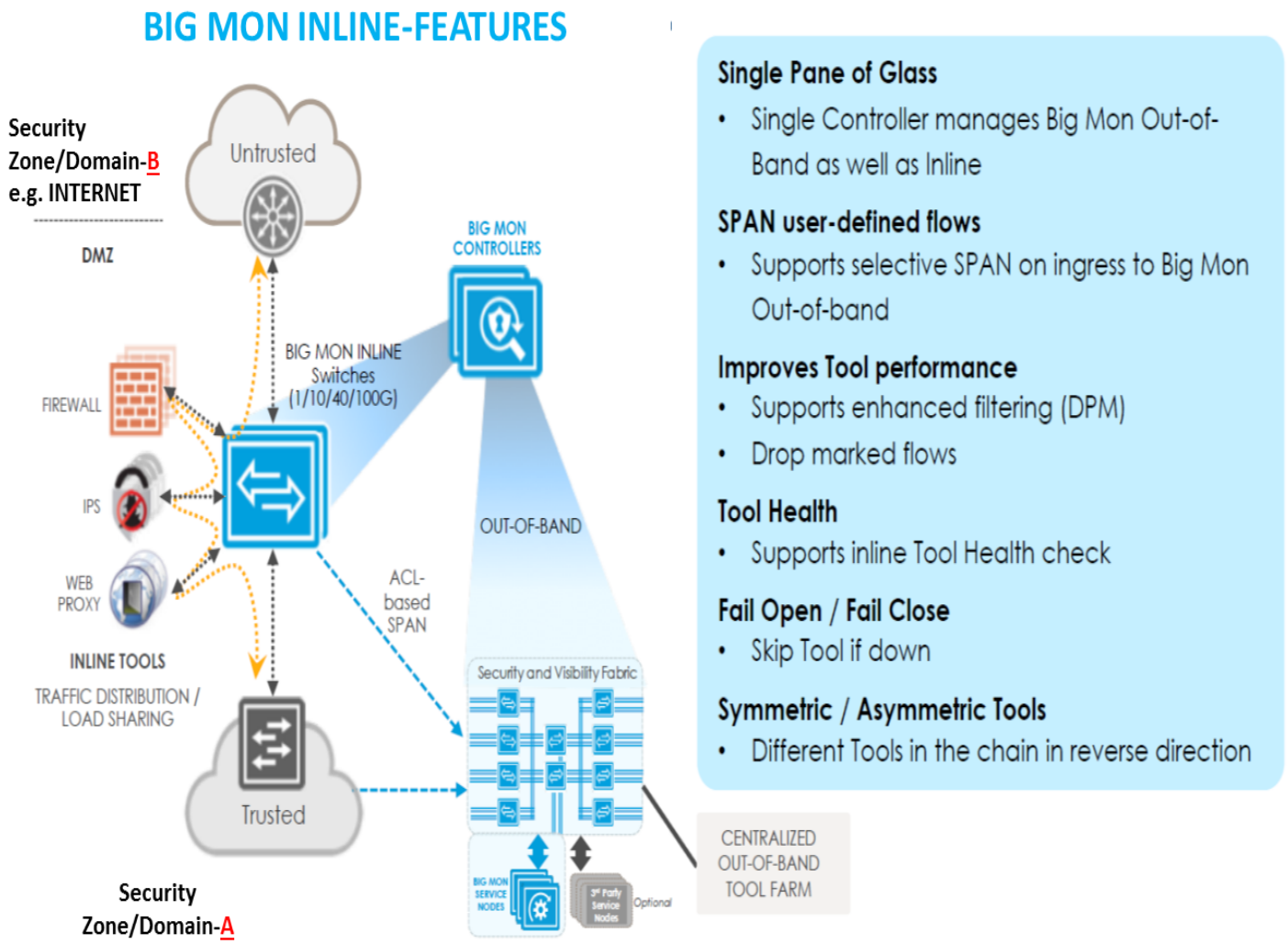


Figure 10: *Big Switch Networks' Big Mon Controller Capability for Integrated In-Line Monitoring and Out-of-Band Monitoring*

The following are the mappings of the Big Switch Components to the GANA Framework and how the Big Switch components fit into the integration framework for GANA Knowledge Plane, SDN Controller for Programmable Traffic Monitoring Fabrics, Programmable Passive TAP & SPAN Aggregation Networks (Fabrics), Automated Test System for Orchestrated Assurance and SLA Violations Detection, and Configuration Tool or SDN Controller(s) for the Production Network(s) (in reference to Figure 7):

- **Big Mon Controller** fulfils the role of a Cloud-First, centralized Controller for Programmable Passive TAP & SPAN Aggregation Networks (Fabrics), an SDN Controller for driving programmability of Traffic Monitoring Fabrics. Big Mon Controller fulfils in part some functionality that could be considered as part of a GANA KP Monitoring-DE, in the sense that it views the Big Mon Fabric Switches and Service Nodes that form the out-of-band monitoring network as its Managed Entities (MEs), and can even manage and control traffic monitoring devices (e.g. firewalls) integrated to operate inline in the production network itself. However, the intelligence for dynamic configuration of traffic morning services can be left to be implemented by another component (e.g. Big Mon Analytics) that would act as the GANA KP Monitoring-DE and would drive the Big Mon Controller (as SDN controller of the Programmable Monitoring Fabric) to configure the traffic monitoring services (behaviors) on the switches.

- **Big Mon Analytics Node(s)** maps (partially) to the role of the GANA KP Monitoring-DE, as Big Mon Analytics Node(s) can be used to implement part of the functionality of a GANA KP Monitoring-DE specified in ETSI TS 103 195-2, else the KP Monitoring-DE can orchestrate and dynamically tune the services of the Big Mon Analytics Node to deliver/stream Analytics results to KP DEs (see Figure 9). Integration APIs of relevance to the 5G PoC are a subject of evolution of such a Traffic Analytics component to fully implement the functionality desirable of a Monitoring-DE specified in the GANA Framework, particularly w.r.t. to driving adaptive traffic monitoring services configurations to fulfill elastic monitoring demands of the GANA Knowledge Plane(s) DEs that rely on knowledge extracted from monitoring data in general, to dynamically configure resources to achieve closed-loop service assurance. In reference to Figure 7, it is desirable that Event Triggered Traffic Capture in the production network be achieved by having the GANA KP Monitoring-DE trigger the creation of SPAN sessions in the production network's switches via the NorthBound API of the SDN controller (s) for the production network and force the SPANed traffic to flow into the out-of-band monitoring Fabric where it is then directed to specific traffic analyzer tools in the Centralized Tool Farm. For example, problems detected on the performance of a particular 5G Slice could result in dynamic SPAN sessions creations to capture certain traffic of interest from the production network. **NOTE:** Big Mon Analytics Node does not create SPAN sessions dynamically on production network switches given that the production network switch (from a different vendor) may not be SDN enabled, but when the production network is based on BCF (Big Cloud Fabric) from Big Switch Networks then it is possible to create SPAN sessions dynamically by interacting with BCF. That said, the Analytics Node can trigger a script in the requisite scenario (concerning dynamic SPAN sessions creations in the production network). The script would then enable creation of a SPAN session(s) on the production switch directly or using a NorthBound API of the SDN controller of the production network to achieve this. Also, there may be a need for dynamic filtering and sourcing of traffic already flowing into TAP&SPAN aggregation network (e.g. from tapped links or sensors in the NEs of the production network) and directing it to specific analytics tools that synthesize knowledge (including forecasts and predictions) and stream the knowledge to the GANA Knowledge Plane DEs that may need the knowledge in their autonomic operations (e.g. executing Remediation Strategies automatically by making certain configuration changes to the Network via SDN Controllers for the Production Network—i.e. performing autonomic(closed-loop) service assurance. The Big Mon Analytics Node can also stream knowledge (including KPIs & Events and Patterns Detected) obtained from its analytics on traffic flows, or even exceptions to the AI-monitored default traffic profile to the GANA KP DEs that may require the knowledge in their decision-making process. This means that the Big Mon Analytics Node can potentially be evolved to implement a full functionality of the GANA KP Monitoring-DE. A GANA KP Monitoring DE is expected to be the component that receives traffic monitoring requests from entities that need monitoring data (or knowledge derived from raw data) and in certain formats and frequency of reception. Entities such as the GANA KP QoS-Management-DE or Security-Management-DE could issue such "traffic monitoring requests" to the GANA KP Monitoring-DE. What this implies is that once a new 5G Network Slice has been created the GANA KP Monitoring-DE needs to be aware of the slice descriptors and scope of the slice (e.g. RAN, MEC, Fronthaul/Backhaul, Core network slice, or whether it is a single VNF as "slice" for example) in order to know how to adapt the currently running monitoring services in order to cater for the Slice monitoring of the newly created slice or to dynamically orchestrate monitoring services via all the instruments necessary and required to monitor and assure the 5G network slice. Therefore, the GANA KP Monitoring-DE as well as the other KP DEs that perform service assurance of the slices need to be "Slice-Aware".
- **Big Mon Fabric Switches and Service Nodes** are considered as Managed Entities (MEs) of Big Mon Controller. Meta Data such as sFlow, NetFlow/IPFIX, that could be associated with an end to end network slice and can be required by the GANA Knowledge Plane DEs or by intermediary analytics platforms that then extract knowledge from the meta-data and feed the knowledge to the KP, can be generated and fed into the recipient systems respectively.
- **Big Mon Recorder Nodes** form a single, logical, scale-out Data Collector on which analytics algorithms can be made to run and synthesize knowledge from raw packets data and stream the knowledge into the GANA Knowledge Plane.

The following are the Main Capabilities of Big Switch Networks that address the specific Objectives outlined above as part of the Requirements for Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring and Feeding of Knowledge into the GANA Knowledge Plane(s) for Autonomic Service Assurance of 5G Network Slices, and Orchestrated Service Monitoring in NFV/Clouds:

1. Capabilities *of* ***Monitoring Data Collectors*** *and* ***Programmable Traffic Monitoring Fabrics in Knowledge Representation and Presentation to the GANA Knowledge Plane*** *(in reference to the RAT (Representation, Acquisition*

and Translation) Function for Knowledge feed into Knowledge Plane. Big Monitoring Fabric (BMF) is capable of delivering actual packets to various collectors, as well as delivering the metadata generated on the basis of these packets to a number of collectors. These collectors include:

a. *Big Monitoring Fabric Recorder Node (RN) – which is a module available in BMF. The main role of the RN is to capture the selected packets in a continuous way and store them for later use. Packets belonging to a particular 5G network slice can be stored on a recorder. Once the packets are captured, Recorder Node can generate PCAP files out of them and specialized analytics algorithms can analyse the raw packets or traces to generate "knowledge" concerning the 5G slice specific certain traffic flow patterns, detected events and behaviours, and stream the knowledge into the GANA Knowledge Planes serviced by the analytics algorithms (software). The device can also replay the packets to any of the tools (e.g. Passive Probe) connected to the fabric (marked in the diagram (Figure 9) above as Centralized Tool Farm). Finally, Recorder Node can run DPI (Deep Packet Inspection) processes on the captured packets to provide even more insight into the contents of the packets, without the need of extracting them outside of the capture device itself. What is most important is that Recorder Node has its own dedicated API which enables automation of all of the actions described above. This API can be used by any third party analytics software that synthesize knowledge from raw packets data and stream the knowledge into the GANA Knowledge Plane (e.g. to DEs that may require the knowledge in their decision-making process).*
   One of the potential uses in the GANA Knowledge Plane is to have periodic API calls fetching data from the DPI process at the Recorder Node, informing the Decision Elements (DEs) about e.g. the health of TCP streams, SIP protocol, used applications, etc. That all can help improve decisions about QoS management of slice specific flows and the NFV platform auto-scaling of resources to improve performance when the knowledge is used to trigger the MANO stack to scale up resource allocations accordingly.
b. *Any tool (e.g. a Passive Probe) receiving packets can be used as delivery elements of packets captured, filtered and optimized by Big Monitoring Fabric (Programmable Traffic Monitoring Fabric). BMF can provide advanced filtering (based on L2/L3/L4 header fields as well as Deep Packet Matching and Regex matching) and optimizations of the packets (deduplication, header stripping, packet slicing, timestamping, data masking, GTP correlation, and more). Thanks to these, the tools will only receive the packets they are actually interested in, in the form they require. The Tools in the Centralized Tool Farm, e.g. Network Performance Monitoring, Application Performance Monitoring, Security Monitoring systems and passive Probes can extract and synthesize knowledge from the analysed traffic and stream the knowledge into the GANA Knowledge Plane DEs that may require the knowledge in their decision-making process on autonomic service assurance of network services (slices). The Tools can be configured to generate and communicate to the Knowledge Plane Meta-Data (e.g. NetFlow, sFlow, IPFIX, etc.), Aggregated Events detected in the analysed traffic, Problem Resolutions (concerning incidents that have been detected earlier and have now resolved), and KPIs pertaining to network performance and application performance (such KPIs can be Slice specific).*

Many of the requirements defined in the Problem Statement are fulfilled by Big Monitoring Fabric. It is a platform which interconnects all of the data sources in both the physical networks and a NFV production network with all the tools and storage units which may require the packets. Thanks to the fact that BMF can be controlled using the REST API, it is a fully programmable fabric. That means the GANA KP Monitoring-DE can program the BMF using the API. Examples of what can be configured using the API:

- *Specify which traffic (from anywhere in the network) needs to be delivered to which (any) tool/storage device*
- *Scheduling of fabric traces to run at the specific time, for given time range or until given number of packets is delivered*
- *Filtering of traffic, slicing packets, replicating packets, load balancing packets, de-duplicating packets, etc.*
- *Delivering not only packets, but also metadata like sFlow, NetFlow/IPFIX and others to data lake collecting metadata (e.g. Big Monitoring Fabric Analytics Node)*
- *At any point in time, packets captured in the Recorder Node can be replayed to any of the tools or be downloaded as PCAP file for other analyser tools*

2. *Capabilities for implementing a* ***GANA Monitoring Decision Element (DE) in the GANA Knowledge Plane*** *and its Integration with SDN Controller for Programmable Traffic Monitoring Fabrics, Programmable Passive TAP & SPAN*

Aggregation Networks (Fabrics), Automated Test System for Orchestrated Assurance and SLA Violations Detection, and Configuration Tool or SDN Controller(s) for the Production Network(s).

a. Using the **Big Mon Analytics Engine of Big Switch Networks** to implement the GANA Monitoring Decision Element (DE) of the GANA Knowledge Plane:
Big Monitoring Fabric Analytics Node (AN) – the metadata / flow collector in the Fabric. It receives flow (sFlow, NetFlow, IPFIX) as well as meta-data information generated by other modules in the Fabric and presents them in clear and adjustable dashboards. Thanks to the data collection, GANA Knowledge Plane DEs can easily extract data of the flows present in the NFV network (e.g. 5G slice specific flows) and present in the physical network segments, their bandwidth, geolocation, quality and performance metrics (e.g. TCP connection setup time). AN is the place where in the future traffic baselining will be implemented. Thanks to this, Analytics Node will understand what is the regular behaviour and traffic patterns in the network, and alert the Knowledge Plane DEs such as QoS Management-DE or Security-Management-DE over standard interfaces about any uncommon behaviours noticed in the NFV network and physical networks.
b. *Any 3rd party sFlow, NetFlow/IPFIX collector can be used to receive the data generated by BMF, which allows for such collectors to be deployed directly within the GANA Knowledge Plane.*

Analytics Node can be a great addition to the Knowledge Plane, as it can be used to implement the GANA KP Monitoring-DE. The metadata captured in it, generated by Big Monitoring Fabric, can be easily exported and consumed by other elements in the Knowledge Plane, such as DEs and ONIX. The generation of Metadata itself can be configured by API to the BMF controller.
AN can create alerts based on threshold and/or baselines computed in its own engines. These alerts are an important addition to the Knowledge Plane (e.g. for DEs to consume and act upon in their decision-making process on autonomic slice assurance). Based on them, KP can become aware of e.g. issues with the quality of services in the production NFV network or the physical network, and as a result trigger reconfiguration of the production network to mitigate the issues. That all creates the closed-loop assurance.

Plenty of requirements in the Problem Statement are fulfilled by BMF AN:
- *Representation of knowledge/metadata in visualized dashboards, and the possibility for the GANA KP DEs to consume the metadata and use in their decision-making process*
- *Interworking with other elements of the KP to create closed-loop assurance of the production networks (including orchestrators)*
- *Detection of poor quality of service, helping ensure all of the SLAs are met, and as illustrated in Figure 8, SLA violations detections can be communicated to Orchestrators to trigger the actions by the MANO to scale up resources for VNFs affected so as the improve the network service performance and fulfil SLAs*
- *Detection of congestions and exhaustion of networking resources in the NFV, helping with network design updates based on changing needs of the workloads, but also sending information about congestion to the MANO stack to enable autonomics within the MANO to react by scaling resources accordingly to remediate the congestion situation.*

Analytics Nodes can be federated in case the scale-out of the Knowledge Plane is required, based on the increasing amount of metadata and processing it needs to perform

3. *The **Integration of Programmable Traffic Monitoring Fabrics (TAP & SPAN Aggregation Switches)** within the broader picture of the Telecom Operator's Desired Framework for Dynamic Probing for Orchestrated Assurance and the Integration/Convergence of Autonomic Service Assurance with Orchestrated Assurance for Newly Instantiated Network Services (e.g. 5G Network Slices and Service Chains)*.
   - *Big Monitoring Fabric is the truly Programmable Monitoring Fabric. Once the physical connections are done to the Physical Infrastructure, and to the tools/storage devices, everything else can be software driven. Mapping of traffic feed to traffic delivery element can be adjusted by BMF controller.*
   - *The controller can use API to exchange information with NFV Orchestrators and Production Infrastructure controllers, to enable and disable some specific traffic feeds and modify delivery rules.*
   - *One of the main benefits of using BMF is its scalability. It can support hundreds-thousands of ports in a single fabric, making it easy to monitor even the largest networks, especially in the context of 5G networks (high link density in Front- and Backhaul, and Core networks)*

4. ***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):*
    - *Big Monitoring Fabric easily connects to the Physical Infrastructure to collect any of the packets traversing the physical links. In NFV infrastructure however, not all the packets can be seen on the physical links. This is why BMF allows integrations with the most popular virtualization platforms, like VMware, OpenStack, Containers.*
    - *When integrated with virtualization environment, the user (or an automated VNF assurance component or Test System) can easily select the workloads/VMs/VNFs whose traffic they want monitored. Big Monitoring Fabric will then use APIs to talk to the respective virtualization environment controller and establish vSPAN/vTAP sessions. That will help extract packets from the compute hosts, deliver them to the physical switches of BMF and further carry on with packet filtering and optimizations as described in the previous paragraphs and points above.*

    - *All such BMF configurations can be further automated by integration of BMF API with the higher-layer orchestration engine (directly or via the GANA Knowledge Plane (i.e. the GANA KP Monitoring-DE)) or indirectly by the Test System for VNF assurance at VNF on-boarding time. BMF can also be made aware of network slices by proper configuration. This will allow to monitor each of the network slices in a dedicated manner, as clearly each of the network slices will have different requirements on both the physical and virtual infrastructure, as well as on the monitoring infrastructure. Big Monitoring Fabric, being the fully programmable tap/aggregation fabric for physical and virtual networks, makes it seamless.*

    BMF in this context can address the following requirements from the Problem Statement:
    - *Integration of monitoring fabric with the orchestration layer to support in the Orchestrated Assurance of newly instantiated VNFs and Service Chains as slices in the NFV environment. When a VNF is created and on boarded, the VNF and/or a newly instantiated service chain needs to be assured by Testing (referring to Figure 8) and hence the need for a test system described in Figure 8. The Test system triggers the MANO to instantiate and configure virtual Probes (both Passive and Active) as well as configuring any vSPAN/vTAP sessions required to test the newly instantiated service (VNF or service chain) and validate the performance of the new service against an SLA, such that any SLA violations result in communication of the test results to the OSS and the Orchestrators that adjust resource allocations for the new service to fulfil the SLA as described earlier (w.r.t Figure 8). Therefore, vSPAN/vTAP sessions can complement virtual passive probes and virtual active probes instantiated to test a newly created service (or slice).*
    - *Orchestrated and dynamic reconfigurations and scale-out of the monitoring fabric, to meet the real-time needs of the production NFV network, taking into consideration all of the immediate changes occurring in the highly-dynamic Telco-Cloud/NFVI*
    - *Ensuring that the monitoring fabric is adjusted to each network slice, from the moment of its creation, to ensuring its proper functioning, to monitoring its quality during regular operations, up till the network slice is removed from the system*
    - *Big Monitoring Fabric, as described in the previous paragraphs, is a great source of metadata/knowledge for the GANA Knowledge Plane, and this metadata can also be generated for the traffic extracted from the VNFs, and made slice-aware*

8. "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

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 diagram below (see Figure 11 below), depending on KP DEs' Algorithms that implementers may determine as viable for the KP to implement autonomic remediation strategies that can be selectively applied either 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.

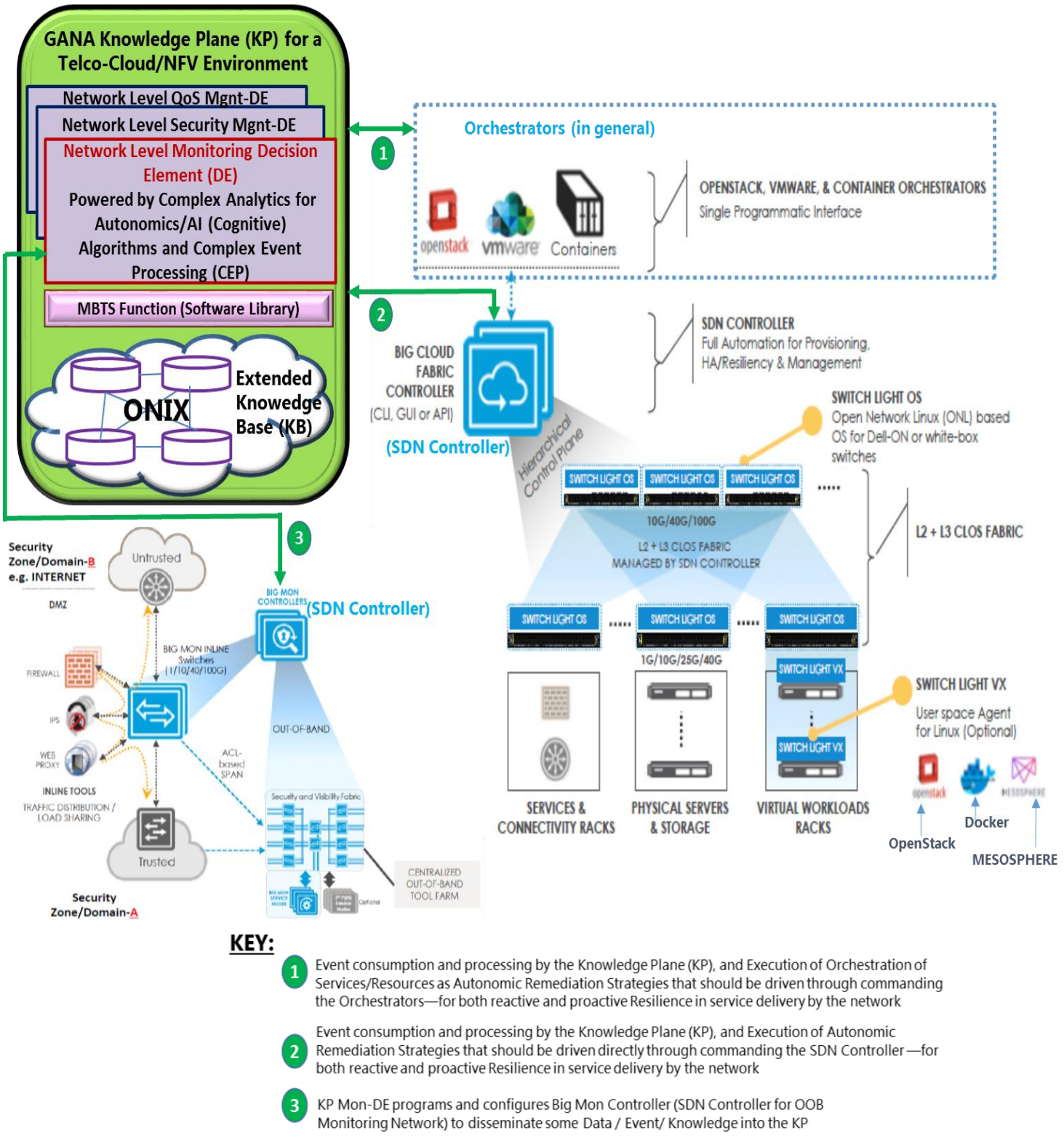


Figure 11: *Big Switch Networks' SDN Controllers (Big Mon and Big Cloud controllers) Capability for Programmability by the GANA Knowledge Plane and Orchestrators*

9. Vendors' Business View of the Overall 5G PoC: Supplying GANA conformant Software for E2E Autonomic (Closed-Loop) Service Assurance for 5G Network Slices and required Programmable Traffic Monitoring Fabrics and Solutions for Orchestrated Assurance

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 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 TR documents on how to introduce 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:** This Demo-3 is mainly focused on Suppliers of GANA conformant Autonomic (Closed-Loop) Service Assurance pertaining to the GANA Knowledge Plane for the Transport Networks and Core Networks, as well as 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).

10. Four Examples of the 5G Applications being considered in the Overall 5G PoC's Network Slicing Use Cases

Remark: Four 5G Applications are considered in the Overall PoC's Network Slicing Use Cases. Whereby, each application (e.g. Smart Insurance Application) is ordering the required Network Slices via an order API interacting with Network Slice Provider's BSS. The table below depicts the mapping between PoC targeted Applications to required Network Slice Types.

Application	Network Slice Type required
Connected Car & Infotainment	• eMBB (SST 1) • uRLLC (SST 2) • IoT (SST 3) • V2X (SST 4)
Car & Home Security & Infotainment	• eMBB (SST 1) • uRLLC (SST 2)

Hayo (IoT) Connected Home Security & Infotainment	• eMBB (SST 1) • uRLLC (SST 2) • IoT (SST 3)
Smart Buildings & Smart Homes	• eMBB (SST 1) • uRLLC (SST 2) • IoT (SST 3)

11. Technical view of the Overall 5G PoC

The plan is to use this 5G Network Slicing PoC as an instrument for the following aims:

(1) Enabling the "Telecom Operators" to provide a clear holistic picture to "Solution Suppliers" as to how their 5G networks would look like and the complementary roles to be played by the following technologies/paradigms in 5G: ETSI GANA components for Closed-Loop (Autonomic) Management & Control of network resources and parameters in Autonomic (Closed-Loop) Service Assurance of Network Slices; SDN; NFV; E2E Orchestrators; Big-Data Analytics for Autonomic/Cognitive Management & Control; SON (Self-Organizing Networks); specialized interfaces (including the network governance interfaces); Network Automation; and GANA intelligence software for Autonomic/ Cognitive management and control of networks and services (i.e. Software for Autonomic (Closed-Loop) Service Assurance); and the Telecom Operator's Desired Framework for Dynamic Probing for Orchestrated Assurance and the Integration/Convergence of Autonomic Service Assurance with the Orchestrated Assurance of Newly Instantiated Network Services such as 5G Network Slices and Service Chains:

(2) Breaking from silos on standards and R&D efforts linked to the complementary emerging networking paradigms, by promoting and progressing the Unifying and Harmonizing Architecture that integrates the ETSI GANA, SDN, NFV, E2E Orchestration, and specialized Big Data Analytics for Autonomic / Cognitive Management & Control;

(3) Enabling "Solution Suppliers" of the following solutions/components and other players to use the PoC instrument to identify gaps in standards and initiate activities (e.g. in ETSI TC INT AFI Working Group) to close any gaps in Autonomic Management & Control (AMC) standards that may be identified during the PoC. "Solution Suppliers" of the following solutions/components are being engaged in the 5G PoC and the various Demos being planned for the 2018/2019 timeframe and beyond:

a. SON (both C-SON and D-SON)—i.e. Centralized SON and Distributed SON (Self-Organization Network);
b. SDN (Software Defined Networking);
c. NFV (Network Functions Virtualization);
d. GANA Knowledge Plane (with the Autonomics/Analytics Algorithms, Knowledge Synthesis and Representation from raw monitoring data, and the dynamic application of various forms of Knowledge obtained from diverse data/information sources by the GANA Knowledge Plane's Decision-making-Elements (DEs) in realizing the *Self-Adaptation (e.g. Self-Optimization) management and control operations for Network Resources and Parameters for the overall Closed-Loop Assurance of Network Slices)*;
e. Probing and Service Assurance Platforms that should act as data/information sources to the GANA Knowledge Plane's DEs,
f. Data Analytics required to be performed or exploited by GANA DEs instantiated (injected) in the network infrastructure Network Elements (physical or virtual) and in the GANA Knowledge Plane;
g. Network Infrastructure Network Elements (Physical and Virtual Network Functions);
h. RAN elements Cloudification Vendors.
i. Traffic Monitoring Solutions Suppliers for Programmable Traffic Monitoring Fabrics that enable On-Demand Monitoring and Feeding of Knowledge into the GANA Knowledge Planes for E2E Autonomic Service Assurance of Network Services (including 5G Network Slices), and Components/Solutions for Orchestrated Service Monitoring in NFV/Clouds

The Figure (Figure 12) below depicts high level design principle of the PoC ecosystem and associated actors/roles relationships and interactions. Two main actors are considered at 5G operation time (run-time):

- a) **Network Slice Provider (SP)** with its associated partners (5G RAN Vendors, 5G X-Haul Network Vendors, 5G Core Network Vendors, 5G OSS & Network Slice Management Software Vendors, Programmable Traffic Monitoring Fabrics Vendors, Probing Vendors, GANA Algorithms and Software Components Developers and Suppliers, 5G BSS Vendors, 5G SON Vendors, …) whose components are required by an SP in creating, delivering, operating and assuring the four Network Slice Types: eMBB (SST 1), uRLLC (SST 2), IoT (SST 3), V2X (SST 4)

- b) **Network Slice Customer** or Network Slice Consumer who orders/ Self-Orders via a dynamic Ordering API the required Network Slice Types according to dynamic SLAs per Network Slice Type by interacting with the Network Slice Provider's BBS (Network Slice Self-Care Portal)

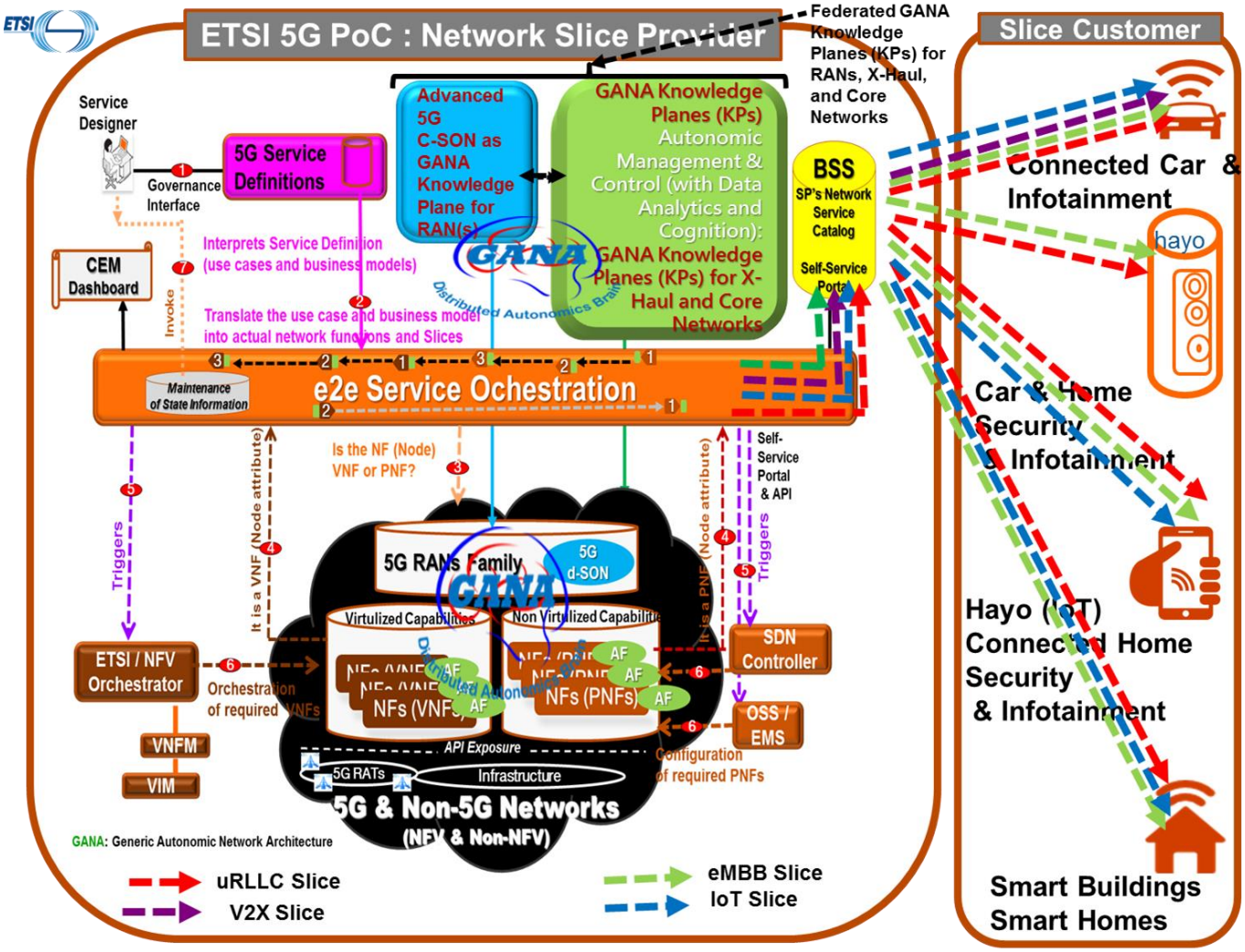


Figure 12: *The depiction of the high level design principle of the 5G PoC ecosystem and associated actors / roles relationships and interactions*

Description of the Network Slice Life Cycle Management (choreography):

1) Slice Designer (Human Operator), via the Governance API, accesses its 5G Slice Design / Service Definition Tool-Chain (pink box) and stores the Network Slice Template once populated, in a repository. **NOTE:** This process is automated in the case of a self-care portal through the BSS that can be used by external customers
2) Network Slice Template is pushed to the E2E Service Orchestrator
3) E2E Service Orchestrator interacts with ETSI MANO components, SDN Controllers and Legacy OSS to translate the content of the Template onto required VNFs / PNFs (RAN ones (including MEC (Mobile Edge Computing) ones) and Core Network ones) which are stored in the Virtualized Capabilities (Network Functions) Repository and in the Non-Virtualized Network Functions Repository (for Core Network). The diagram shows a dedicated Repository for RAN capabilities. All those capabilities are executed on the substrate layer (Hybrid Infrastructure: Black Cloud)
4) The descriptions (descriptors) of the identified (the required) VNFs and PNFs are sent to E2E Service Orchestrator
5) E2E Service Orchestrator launches Network Slice Life Cycle Management process
6) The Network Slices ordered by the customers via Service Provider's BSS (Yellow Box) are instantiated, configured and delivered to each of the four Customers (represented by the 5G applications) at the right hand side of the diagram.
7) GANA Knowledge Plane and "Distributed GANA" (Green boxes) DEs embedded in the VNFs and PNFs as AI / ML/ Cognitive algorithms along with Hybrid SON (Centralized and distributed: Blue Boxes) take care of configuration of the NEs (Network Elements, i.e. PNFs and VNFs) in the infrastructure if not already performed through the traditional management systems, and then proceed to perform E2E federated Autonomic (Closed-Loop) and Cognitive "Service Assurance" of each Network Slice Instance a Customer is consuming.
8) BSS (Yellow Box) embeds the Network Slice Billing System that shall offer billing capabilities per Network Slice Instance, enabling the billing of each Network Slice Instance individually, in the same way as a 5G OSS that shall offer management capabilities per Network Slice instance as an "Individual (sole) Network Slice Instance Manager"

12. QoS Framework on Flow-Oriented (Flow-Level) Services & Telemetry Services delivered within a specific 5G Slice Type and varying in QoS Classes; Prioritization of Slices; and Definitions of QoS Classes and SLAs as inputs to Autonomic Service Assurance

Network Operators expect to deliver a mix of different types of 5G network slices to diverse kinds of customers. Examples of such 5G slices types include Man-Machine-Communication (MMC) slice and Machine-to-Machine (M2M) slice, with need to consider Access Class Lists assignments to the slices as illustrated below and in Figure 13. **NOTE:** The slice types used in the illustrations in this section are not necessarily the slice types specified by 3GPP (so far 3GPP specified three types of slices) but, 3GPP does not exclude a Telecom/PLMN Operator from the flexibility to specify its own slice types (a case illustrated here):

- **MMC Slice**: Network Slice with Man-Machine-Communication Factor; Examples of Sub-Services (Flow-Oriented (e.g. IP Flow-Level) Services)) the Slice may carry:
  - Premium Video Services
  - Premium Audio Services
  - Regular Multimedia Services with User Profiling/QoS (Audio, Video)
- **M2M Slice**: Network Slice with Machine-to-Machine Operation Mode; Examples:
  - Automated Measurements of certain Metrics (e.g. KPIs) of relevance to M2M services delivered by the Slice
  - Statistics Collection & Monitoring Applications that are associated with the Slice and its performance on M2M services delivery
- **Ac.Cl.: Access Class List (4G/5G)**

On how to package services (e.g. Flow-Oriented (Flow-Level) Services & Telemetry Services) into Slices:

- Services are grouped into categories whereby each service is delivered within the scope of one network slice and is allocated to a particular group

- Groups are of either MMC or M2M type and carry a priority label
- Each network slice allocated to a service is dimensioned so that its resources match the service requirements (Bandwidth (BW), Service Level Agreement (SLA))
- As more services run on the network in slices, new services will contend for resources; and so a flexible QoS provisioning framework is required to be in place and is expected to handle resource management and orchestration of the services via admission control, resource reallocation.
- Possible plots are: a service is denied access, slice widths are reassigned to fit a new service, a service is frozen to fit in a new slot, and queueing of a current lower priority service until resources are available.

As described in section 6.4, the ***QoS-Management Decision Element (DE) of the Knowledge Plane (KP) responsible for a particular network segment(domain)*** is the **Autonomic Manager Component** 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.

Figure 13 below provides an illustration of the concepts of Network Slice Width, Slice Prioritization, Services Grouping and allocation to Slices and Access Class List (Ac.CL) mappings to Flow-Oriented (flow-level) Services running within a particular slice. What this means is that such a QoS Framework helps the Network Operator to produce *Definitions of QoS Classes and SLAs* (as QoS Profiles) that are then fed as inputs to Autonomic Service Assurance by each of the GANA Knowledge Planes (KPs) involved in E2E Federated Autonomic Service Assurance of 5G Slices and their sub-services they carry. QoS Profiles (which include SLAs and Customer Identifiers Information/Data) should be communicated from the Service Fulfilment functions (e.g. BSS) to the Autonomic Service Assurance Functions (i.e. the GANA Knowledge Planes (KPs)), with each KP being responsible for autonomic service assurance that covers a particular network segment under the management and control by the KP. While the KPs federate to collaborate on E2E Cross-Domain Autonomic Service Assurance. Section 14 and [7] provide more insights on E2E Autonomic Service Assurance by Federated GANA Knowledge Planes (KPs) for various individual network segments. Each GANA Knowledge Plane for a particular network segment uses the mappings of the QoS Classes and associated SLAs 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 (re)-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 network segments to determine collective actions that should be performed by the KPs to guarantee global SLAs for E2E Aggregate 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) on performance and telemetry/monitoring data (e.g. KPIs) concerning Slices under its autonomic service assurance responsibility. As illustrated in section 7 and in [7], 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.

Regarding KPIs related to specific slices, slice monitoring solutions implementations should consider presenting both, aggregate KPIs that reflect the overall performance of a slice and also KPIs related to the sub-services within a slice and the associations to customer identifiers data and SLAs. Regarding telemetry, telemetry/monitoring data concerning slices and their sub-services, OOB solutions (such as the one presented earlier) 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).

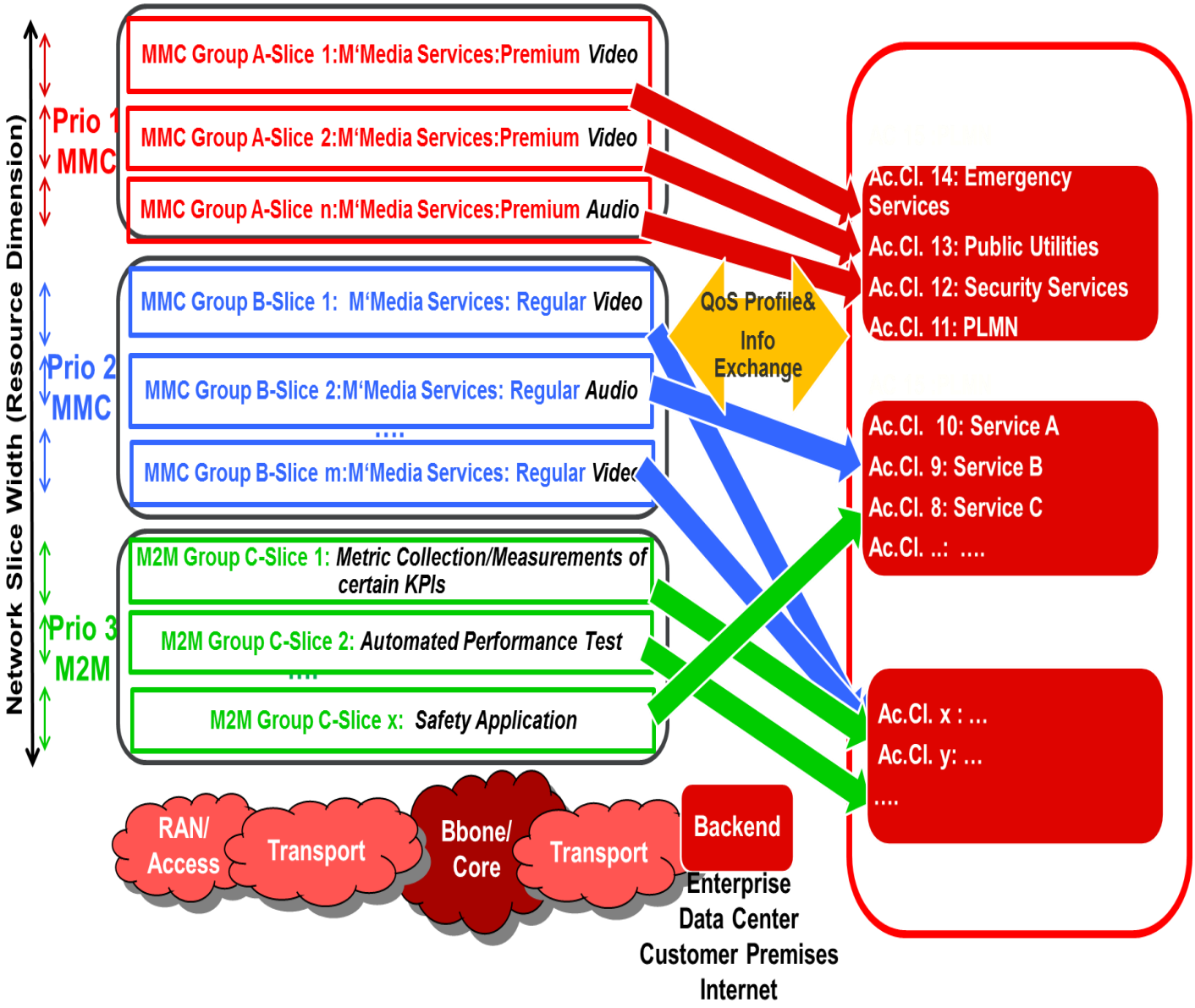


Figure 13: *Illustration of the concepts of Network Slice Width; Slice Prioritization; Services Grouping and allocation to Slices; and Access Class List (Ac.CL) mappings to Flow-Oriented (Flow-Level) Services (e.g. Customer IP Flow Services and Telemetry Services, Performance Test Services and specialized Application Flows) running within a particular Slice*

NOTE: "info **exchange**" in the Figure 13 is about the communication of QoS Profiles from the BSS (Service Fulfilment Function) to the Autonomic Service Assurance Functions (i.e. the GANA Knowledge Planes (KPs))—with each particular network segment having its own KP that federates with KPs for the other network segments, and also relates to the communication of Slice related service performance data and events from telemetry functions.

The following Table (**Table 1**) illustrates some of the aspects that should be considered when assessing the viability and performance of a use case involving the delivery of a mix of MMC slices and M2M slices. With such a Use Case, micro-operators (MVNOs) and other players can use such 5G Slicing Mechanisms with dynamic QoS in order to use their limited spectrum more efficiently and handle more subscribers with higher efficiency.

Table 1: Aspects that should be considered when assessing the viability and performance of a use case involving a mix of MMC Slice and M2M Slice

Use Case: Mixed MMC & M2M Scenario	Key Feature(s)	Example aspects for consideration in assessing such a Use Case
Users and M2M Entities share the network resources in the form of slices (E2E) up to a certain utilization factor. When/before a new service is initiated, a resource availability check is performed and then the service is launched within the allocate slice. Admission Control (AC) is a gateway/gatekeeper mechanism to allow a slice to be formed in the resource stack before a service is launched. Depending on the load and resource availability situation, the AC decision is made.	Admission Control	Service/Slice Creation Service/Slice Denial Service/Slice Reshaping before Admission → **QoS Gatekeeper**
When a high network resource utilization factor is reached, the QoS mechanisms that handle the network slices should be able to reallocate resources among different slices for optimizing resource management. When a service from a high-priority group wants to join the network, the Resource (re)-Allocation (RA) mechanism negotiates with the AC mechanism	Dynamic Resource (Re)alloc.	→ **Flexible QoS**
A network slice can be frozen (e.g. a slice wholy occupied by a certain type of measurement application)	Slice Blocking/ Removal	→ **Slice Preemption, Slice/Service Queueing**

13. ETSI-GANA Model as key Enabler for 5G: High Level Design Principle

The AFI Working Group in ETSI's INT Technical Committee (TC) (previously hosted in ETSI TC NTECH), as the leading group in the standardization landscape for Autonomic / Cognitive Management & Control of Networks and Services, has a comprehensive work programme which comprises deliverables on: a reference model for a Generic Autonomic Network Architecture (GANA); an implementation guide for the GANA reference model; and autonomics-enabled implementation-oriented network architectures and their associated management and control architectures that are a result of GANA instantiations onto various reference network architectures and their associated management and control architectures defined by standardization organizations such as 3GPP, BBF, IEEE, ITU-T and other Standards Developing Organizations (SDOs). The following ETSI White Paper summarizes the activities and deliverables:
http://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp16_gana_Ed1_20161011.pdf

Indeed, ETSI TC INT AFI WG has made significant progress in developing standards that prescribe methods and mechanisms for introducing "intelligence" in the management and control operations of networks and services and on how to operationalize

GANA. Namely the application of the "Autonomics" paradigm, with the goal of prescribing design and operational principles for self-managing and self-adaptive networks that enable to achieve OPEX reduction through Autonomic & Cognitive Fulfillment & Service Assurance(see http://appledoreresearch.com/product/closed-loop-automation-new-role-assurance-research-note/)

Other benefits "Autonomics" brings to Network Operators such as creation of new revenue stream in 5G arena where Autonomics and specifically GANA can be key Enabler: http://www.iwpc.org/workshops/2016/2016-06-DT/agenda.html

More Background Details on the ETSI TC-INT/AFI WG 5G Network Slicing PoC (with Autonomic (Closed-Loop) Service Assurance for Slices) and 5G PoCs landscape:

After the first 5G related standardization round (NGMN's 5G White Paper, E2E 5G Architecture, SCT), 3GPP (R14, R15) efforts that took off, ITU efforts on 5G that took off, and the initial 5G roadmaps that were laid out by the diverse players in 5G, an acceleration process was undertaken in 2017. Most of key Mobile Operators are pushing things this way by announcing aggressive roadmaps and seizing key events (sport related) to use them as 5G playgrounds where all 5G players try to deliver their best products and solutions and to demonstrate the first benefit 5G brings and the huge promises and perspectives on how 5G will nicely complement 4G. This acceleration will pave the way for the commercial deployment of 5G.

From Testing & Trialing side, various initiatives have been launched and there is a need for harmonization in terms of methodology, assessment approaches, interoperability, KPIs consolidation as a foundation to facilitate this move. This is the reason why this ETSI INT 5G Network Slicing PoC aims at collaborating and liaising with other industry driven 5G PoCs initiatives but not limited to initiatives such as NGMN 5G_TTI, TMForum "5G Service Operations" Catalyst, and BroadBand Forum (BBF) 5G related PoCs programs.

14. 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 Multi-Domain State Correlation and adaptive resources programming*" by the **GANA KPs** for ***Access***, ***Backhaul***, and ***Core Networks*** *(as illustrated below (see* Figure 14*)). 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].
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 the mappings of QoS Classes and associated SLAs 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 performance and telemetry/monitoring data (e.g. KPIs) concerning Slices (e.g. Access Network Slices, X-Haul Slices, etc.) under its autonomic service assurance responsibility, and relying on various kinds of telemetry data of relevance to those slices as discussed in section 12.

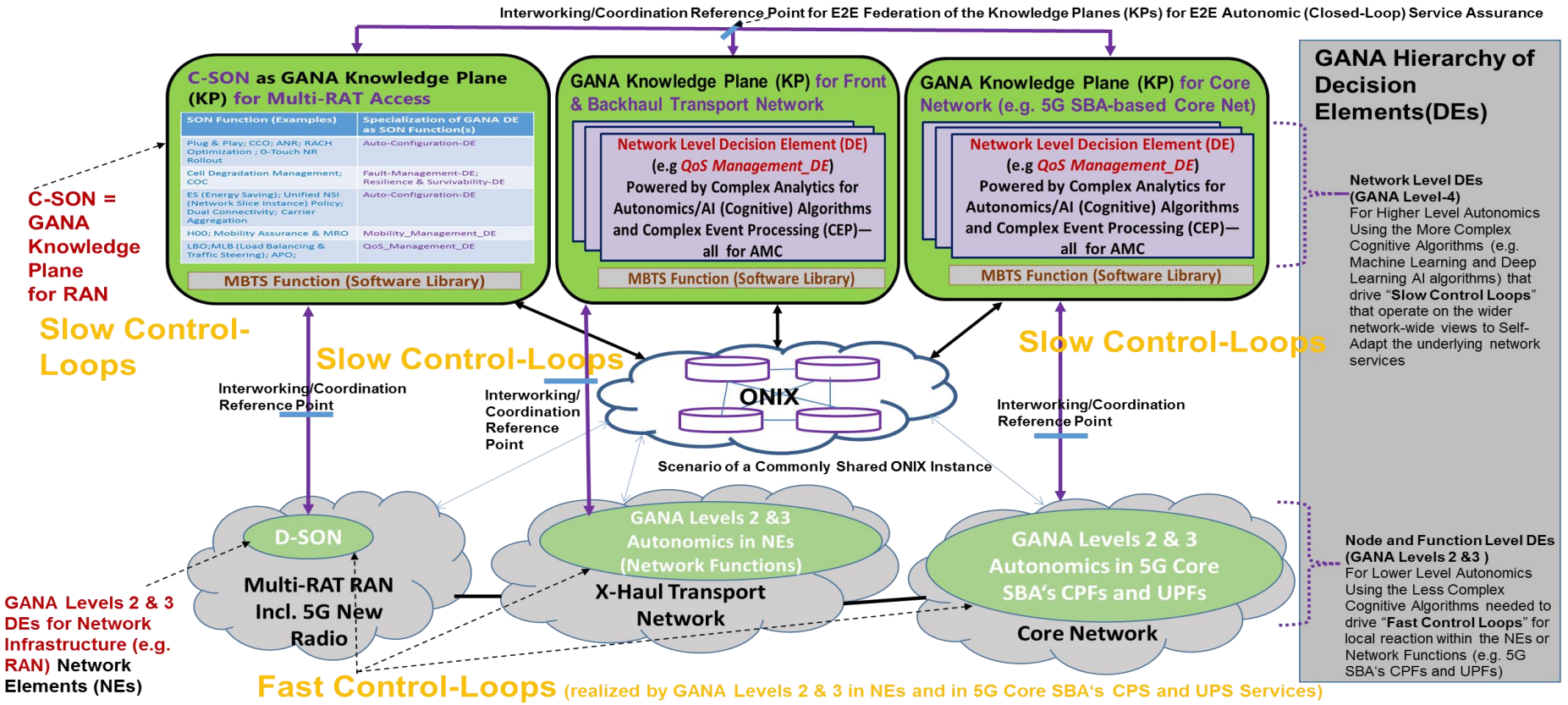


Figure 14: Framework for E2E Autonomic(Closed-Loop) Service Assurance of Network Services through the Federation of GANA Knowledge Planes (KPs) for various segments: RAN (C-SON), Front-/Backhaul, Core Network, etc., and complemented by lower level autonomics in Network Elements (NEs) or Network Functions(NFs)

15. Conclusions

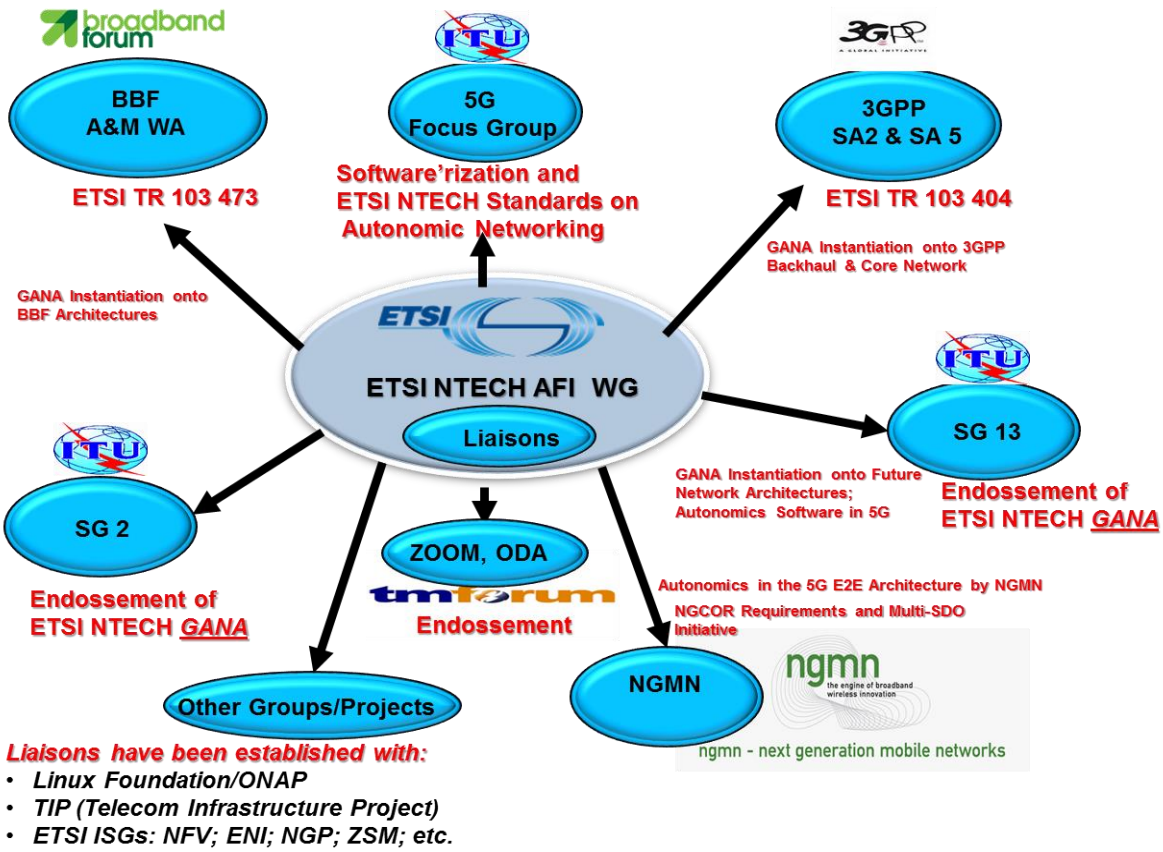
The Demo-3 of the ETSI 5G PoC is expected to produce a Report that describes the results and discussions outcome of the Demo-3 in terms of the Objectives of Demo-3 outlined in this White Paper and the Network Operator's Requirements listed in the Problem Statement section of this White Paper. Therefore, readers are encouraged to follow the developments, progression and the results (Demo Reports (e.g. Demo-3 Report)) of the ETSI 5G PoC that are to be made available at https://intwiki.etsi.org/index.php?title=Accepted_PoC_proposals [3], as the full Report of the Demo-3 can be downloaded from the URL soon, and there are plans for more demos as part of Demo series planned for the overall PoC in the timeframe 2018/2019 and beyond).

16. Further Work (beyond Demo-3) on Programmable Traffic Monitoring Services in NFV environments

As further work on the topic of programmable traffic monitoring, it is envisaged that this PoC will explore further the use cloud-native services in place of traditional VM-based cloud services, particularly in the case of the need to deploy monitoring components (especially agents, probes) within a shorter time scale, and when it becomes needed to scale up (and down) computing resources required by VNFs in a very short time scale, e.g. within hundreds of milliseconds or a few seconds. And also the considerations for much more complex dataflow-based distributed stream processing aspects.

17. On ETSI TC INT AFI WG and its Liaisons with other SDOs/Fora on GANA Autonomics in various Architecture Scenarios

ETSI TC INT AFI WG (previously called TC NTECH AFI WG) has established liaisons with various SDOs/Fora on the introduction of GANA autonomics in various network architectures and associated management & control architectures, and with Open Source Projects as well, as shown on the picture below. ETSI TC INT AFI WG seeks to continue to establish liaisons with various groups and projects working on emerging and future network technologies.



18. 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

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[6] Drissa Houatra, Yuchia Tseng: Monitoring 5G radio access networks with cloud-based stream processing platforms: Published in IEEE Proceedings of 2018 21st Conference on Innovation in Clouds, Internet and Networks and Workshops (ICIN), 19-22 Feb. 2018, Paris, France: **DOI: 10.1109/ICIN.2018.8401581**

[7] 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

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The ETSI 5G PoC Consortium:

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- Big Switch Networks

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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