Network Management and Orchestration Using Artificial Intelligence: Overview of ETSI ENI

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Abstract

The European Telecommunications Standards Institute launched the Industry Specification Group on Experiential Networked Intelligence in February 2017. This article provides a comprehensive review of the status of this work, including the work on use cases, requirements, reference architecture, and proof of concept, and gives insights regarding its future direction.

Introduction

With the significantly increased complexity of current and future networks, operators see human-machine interaction as slow, error-prone, expensive, and cumbersome. For example, operators are worried about the increasing complexity of integration of different platforms in their network and operational environment; this is due to the vast differences inherent in configuring different devices as well as the difficulty in building agile, personalized services that can be easily created and torn down. These human-machine interaction challenges are considered by operators as barriers to reducing the time to market of innovative and advanced services. Moreover, there is no efficient and extensible standards-based mechanism to provide services that are adaptable to changes in user needs, business goals, or environmental conditions. These and other factors contribute to a very high operational expenditure (OPEX) for network management.

Operators need the ability to automate their network configuration, optimization, and monitoring processes to reduce this OPEX. Such requirements pose significant challenges (e.g., automating the complex human-dependent decision making processes, determining which services should be offered and which services are in danger of not meeting their service level agreements [SLAs], as well as visualizing network telemetry to gain further insight into service and resource fault management and performance).

The purpose of the European Telecommunications Standards Institute (ETSI) Industry Specification Group (ISG) on Experiential Networked Intelligence (ENI) [1][2] is to define an architecture that uses artificial intelligence (AI) techniques and context-aware, metadata-driven policies to adjust offered services based on changes in user needs, environmental conditions, and business goals, according to the "observe-orient-decide-act" control loop model [3]. The focus of the ISG is to improve the operator experience, to recognize and incorporate new and changed knowledge more quickly, and hence make quicker and more effective actionable decisions in day-to-day-operations.

ENI presently has members and participants involving industry and research institutes. Since its start in February 2017, the ISG has been specifying a set of use cases and the derived requirements for a generic, technology-independent system architecture. A gap analysis of ENI work on context-aware and policy-based standards has been carried out. A high-level architecture that uses AI mechanisms to learn and make decisions is being specified, and a work item to create one or more proofs of concept (PoCs) has also been established.

The current article presents the work that has been carried out in ENI, and provides the envisaged activities for the near future. Use cases and requirements are provided in the following two sections, respectively. Context-aware gap analysis is detailed next, and the current progress on reference architecture is then given. Finally, we give examples of the PoC activities in ENI, and conclusions are given in the final section.

Use Cases

Use cases drive the definition of ENI Requirements and Reference Architecture. So far, 13 use cases have been defined as examples of how ENI systems can benefit network operators. These use cases cover a wide range of fixed and mobile telecommunication systems, with applications in the radio access network (RAN), fronthaul, and core network. The use cases cover four categories, including Infrastructure Management, Network Operations, Service Orchestration and Management, and Network Assurance. Interested readers are referred to [4] for detailed descriptions of all use cases identified in ENI. In the following, three example use cases will be provided in detail to show the potential benefits of ENI and the use of AI in networks.

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Energy Optimization with the ENI System

Power consumption is reported to occupy a majority share of the network OPEX, among which the data center (DC), made up of a large number of servers, can take 70 percent of the total power consumption. The servers are deployed and run to meet the requirement of peak hour service, which means they are usually in a high power-up state at full time even in non-peak hours. It is, however, possible to move the services to some of the servers and turn the remaining servers to an idle state in non-peak hours, which optimizes the power usage in the DC.

Traditional methods of DC energy saving are normally done manually. Consisting primarily of a configurable server pool, the scope of what can be optimized in an intra-DC context is limited. However, it is a necessary first step toward greater AI-driven improvements that can be achieved with the additional consideration of both inter-DC orchestration and the exploitation of network resource pools. The consideration of these additional factors will enable the minimization of the carbon footprint through intelligent resource management. For example, by relying solely on edge device compute resources in periods of low demand, an ENI system could identify and act based on these requirements in an autonomous way, ensuring that OPEX is optimized.

By using an ENI system, the usage pattern of the services can be learned from historical data and updated in real time. The ENI system can help to trigger the movement of the services and turn the spare servers to an idle state. As shown in Figure 1, the actual load of service in one day is represented by the curve; the distance between the peak and valley of the curve indicates the potential energy saving for the DC.

In addition, the ENI system can predict the peak hours by using AI techniques such as deep learning and machine learning, and wake up the necessary number of servers into a full load state. If an unexpected event is detected, more servers can be woken up to support this burst.

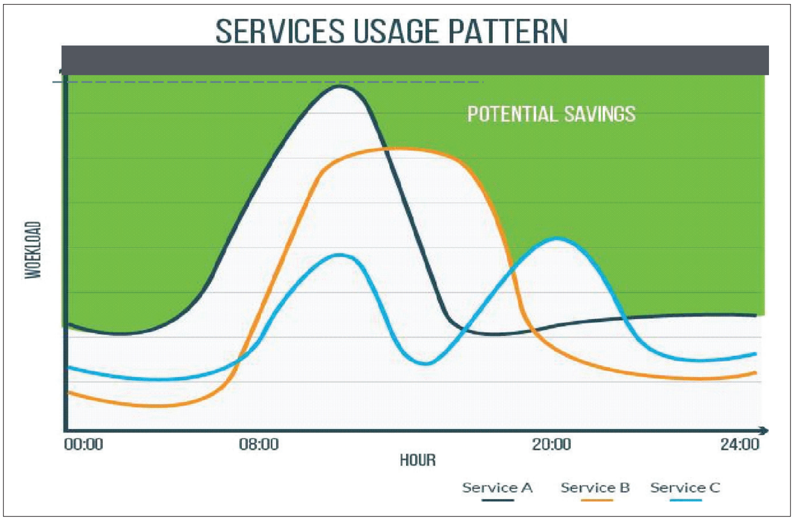

Figure 1. DC energy saving using AI.

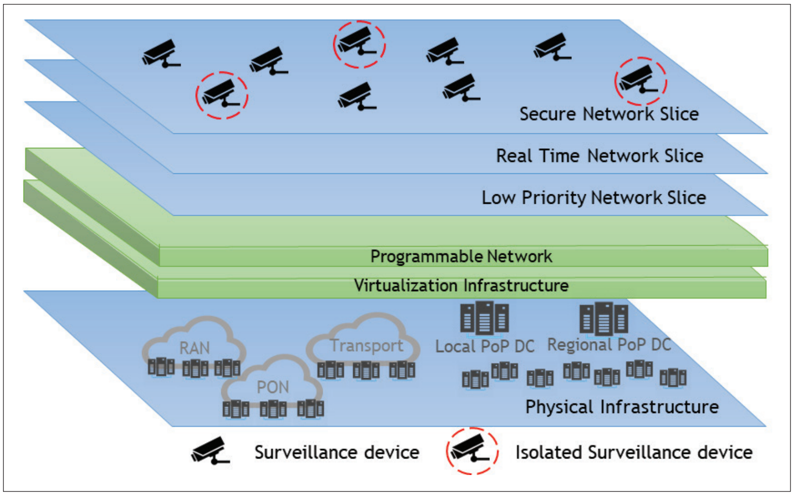

Figure 2. Policy-based network slicing for IoT security.

Policy-Based Network Slicing for IoT Security

Smart cities are expected to be built using a myriad of Internet of Things (IoT) devices, where a significant number of them will be connected through fifth generation (5G) networks. These devices will play a vital role in the deployment of various services. To support this massive deployment of devices, the use of network slices will enable their aggregation either by functionality (e.g., security or city operations management support) or by other types of lower-level requirements, such as low latency and high bandwidth. In this context, the handling of distributed denial of service (DDoS) attacks plays a crucial role as those devices are usually meant to be part of the support to applications/services related to social interest.

An ENI system can be used to detect specific traffic patterns indicating DDoS or other types of attacks. This is because the increasing sophistication of such attacks makes it harder to use simpler algorithms (e.g., pattern recognition) that focus on a set of predefined information. The symptoms of a DDoS attack include unusually slow network performance and/or the inability to access a particular set of web sites. When this happens, the ENI system will be able to detect and learn from the occurrence by using AI methods. If the new traffic pattern is identified as an attack based on past history, the ENI system will trigger appropriate responses from the related management components. In addition, AI enables different types of attacks to be correlated. For example, different attacks could use different protocols, but all be directed at the same target. By using those techniques, the ENI System will be able to identify these and other types of attacks with a shorter timeframe and better precision when compared to today's systems.

Figure 2 provides a pictorial representation of this use case, with the isolation of a network device once suspicious traffic behavior is detected by the ENI system.

Intelligent Fronthaul Management and Orchestration

Slicing of network resources at the fronthaul between remote and centralized units can be complex, especially in a dynamic and flexible manner, as it is affected by multiple factors and

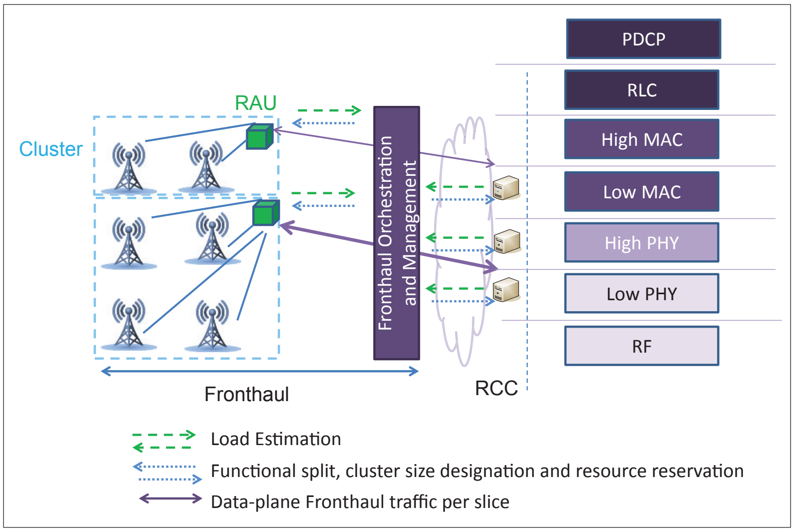

FIGURE 3. Intelligent fronthaul management and orchestration.

associated changing contexts. Examples include the clustering on the remote units, the functional split between remote and centralized entities, and the dimensionality of the solution space on network resources to be reserved in the fronthaul. This latter includes power, processing capability, radio resources, buffering memory, and route to be selected.

The application of AI under such context will bring efficient management and orchestration optimization by balancing the multiple aspects considered on network resource slicing mentioned above. It will also enable flexible and dynamic resource slicing and functional split at the fronthaul, considering the changing contexts of the network, such as changing traffic demand at the remote aggregation units (RAUs) and radio cloud center (RCC). As an example of such an application, through load estimation and prediction by using the state-of-the-art AI algorithms, the fronthaul management and orchestration can also be designed in an "on-demand" manner as shown in Figure 3.

Requirements

ENI specifies requirements that are derived from the use cases and impact the design of system architecture. The ENI system requirements are classified into three categories.

Service and network requirements, which are addressed from a service and network point of view. These include:

a. Requirements on ENI system service provisioning (e.g., how to construct services and their monitoring to ensure that appropriate contract commitments, such as SLAs, are not violated).
b. Requirements on network planning and deployment (e.g., how to allocate network resources to virtualized network functions [VNFs] or how to perform automatic VNF onboarding.
c. Requirements on network optimization (e.g., how to adjust the network configurations to improve its efficiency and performance, as well as the user experience of the service).
d. Requirements on resilience and reliability of the network (e.g., fault diagnosis and prediction, high availability and backup, conflict detection, and rolling back to enforce previous policies and service status).
e. Requirements on security and privacy issues (e.g., data collection captured in a secure way without adding security risks). Moreover, it is recommended that the collected data shall be accessible by authorized accounts, and that privacy of both subscribers and operators is protected.

Functional requirements, which are addressed from an architecture point of view. These include:

a. Requirements on how data is collected and analyzed by the ENI system
b. Requirements on how policies are managed and used by the ENI system
c. Requirements on how data learning is performed in the ENI system
d. Requirements on how the ENI system interworks with other systems

Non-functional requirements, which include:

a. Performance requirements (e.g., latency, accuracy, efficiency)
b. Operational requirements regarding reusability, extensibility, and energy saving
c. Regulatory requirements (e.g., lawful interception and data protection)
d. Non-functional policy requirements

All of the requirements provide guideline principles on architecture design. In the following, five of the ENI requirements are selected as examples to show how they affect the overall architecture design. All requirements specified for the ENI system can be found in [5].

Data Collection and Analysis

The intelligence of the ENI system is reflected in the capability to acquire knowledge based in part on the data collected from the network. The network itself is a huge database to be mined. What kind of data the ENI system collects, and how it uses these data should be defined by the ENI architecture, and should be use-case-oriented. Thus, abstracted from the identified ENI use cases, a few requirements regarding data collection and analysis have been specified. These include information on network status data related to connection or routing protocols in use, or network context information (e.g., time of day, device/link state, and location of users), which shall be collected from the infrastructure. This means there will be interfaces between the ENI system and the network infrastructure to collect these data, directly or indirectly, which will be defined during the ENI system architecture design.

Support of Closed Loop Control

The ENI system provides network control, management and orchestration recommendations, and/or commands. The purpose is to modify the behavior of the underlying network in order to improve the delivery and reliability of services, hence contributing to a better user and network experience.

This is achieved by making use of multiple closed control loops throughout the ENI system. The ENI closed control loops are based on the observe-orient-decide-act paradigm, which has been extended to include AI mechanisms to better monitor, analyze, and predict what the system will do, and how to ensure that business goals are met in the face of change.

Network Service Fault Prediction

The ENI system, when analyzing the collected data, must be able to detect, predict, and learn from data that represent both proper and faulty network operations. This is enhanced by using AI methods. Together with context awareness, this identification allows the pro-active generation of policies that may avoid or at least mitigate problems with delivered services that degrade the user's experience.

Context Awareness and Policy Management

The outputs of the ENI system are always based on the context of the system being managed. Further details on these two concepts may be found later in this article, including their impact and their role in the architecture design.

Interworking with Other Systems

The relationship between the ENI system and other network systems will be defined during the design of the ENI architecture. The identified interworking requirements with those other systems impact the way the ENI system fits into the overall network framework. Among others, there are two important requirements regarding this aspect.

First, the ENI system needs to interwork with other systems by reusing existing interfaces as much as possible. In this context, the word "interwork" means that the ENI system will be designed as a standalone system, communicating with other existing systems by reference points/interfaces.

Second, it has to be assumed that a possible failure of the ENI system should not interrupt the services provided by other systems. This means the ENI system should be designed to interwork with other systems in an offline mode, as a parallel assistant system to existing systems.

Policy Modeling and Context Awareness

One of the primary goals of ENI is to ensure that business goals and objectives are not threatened by changes in the network (e.g., outages or resource failures), as well as changes in user needs, business goals, and environmental conditions. To achieve this, ENI makes use of context-aware policy management.

Past definitions of context (e.g., [6]) have a number of shortcomings when applied to modern system and network management. Therefore, the definition of context used in ENI is: "The Context of an Entity is a collection of measured and inferred knowledge that describe the state and environment in which an Entity exists or has existed" [7].

This definition emphasizes two types of knowledge:

- Facts: data that can be measured in a particular context
- Inferences: data that results from some reasoning process applied to past and/or current contextual data

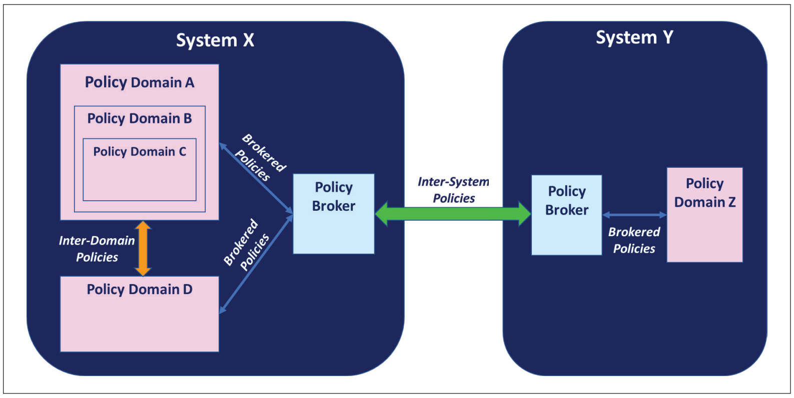

Figure 4. Policies used in management and control vs negotiation.

It also includes context history, so current decisions based on context may benefit from past decisions, as well as observation of how the environment has changed. We model context in the system so that the Policy Management system can detect and respond to changes in context. The purpose of policies is to ensure that consistent decisions are made governing the behavior of a system. ENI uses the following definition of Policy: "Policy is a set of rules that is used to manage and control the changing and/or maintaining of the state of one or more managed objects" [7].

Policies may be Intra-Domain (e.g., Policies exchanged between domains A and B or domains B and C, as shown in Figure 4), Inter-Domain (e.g., between domains A and D, or between B and D or C and D), or Inter-System (e.g., between system X and system Y). Networks can be managed using policy, as it is a natural way to express rules and restrictions on behavior. However, the number of policies can be very large (e.g., 100,000+) and the relationships between them very complex.

ENI performed an analysis of existing work done in various standards development organizations (SDOs) on policy and policy management in general, and context-aware policy management specifically, to determine what can be reused and what needs to be developed within ENI [9]. The starting point for the policy management and modeling in ENI has been the work done for the forthcoming Metro Ethernet Forum (MEF) Technical Specification: Policy-Driven Orchestration (PDO) [8]. This work is considered to represent a good sampling of the state of the art in policy management and informed the creation of a set of key requirements for the ENI context-aware policy management model.

The results obtained during the analysis feed directly into the approach taken during the architecture design work. For a detailed report of the ENI policy modeling and context awareness gap analysis, please refer to [9].

ENI Reference Architecture

ENI is conceptually a system that assists other systems in making more informed decisions. This is depicted by showing the interaction of an ENI system as a separate system that gets data from, and provides information (including suggested commands) to, the existing system.

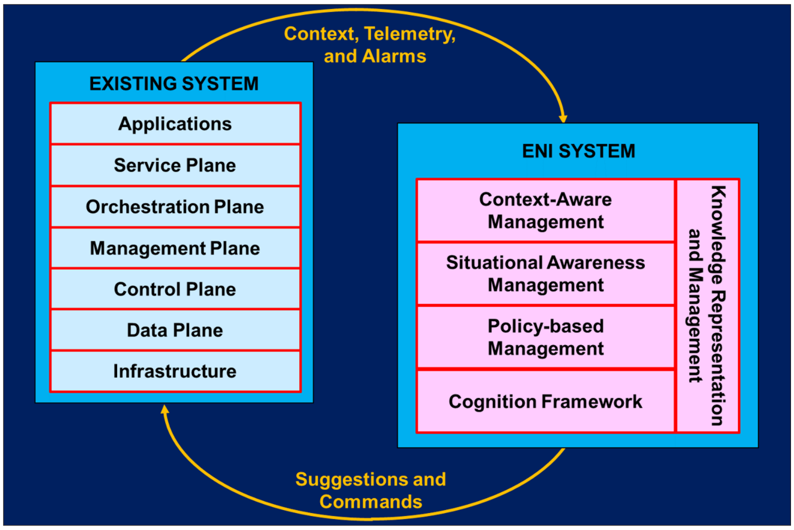

FIGURE 5. High level functional architecture of ENI..

ENI is conceptually a system that may perform two different roles, as described later. An ENI system is not solely a controller, manager, or orchestrator; rather, it sends information and commands to multiple planes (as shown in Fig. 4a) depending on its mode of operation. This is depicted by showing the interaction of an ENI system as a separate system that gets data from, and provides information (including suggested commands) to, the existing system.

We describe the functional blocks in ENI architecture in detail in the following subsections.

Knowledge Representation and Management Functional Block

The purpose of the Knowledge Representation and Management Functional Block is to represent information about both the ENI system as well as the system being managed. This includes differentiating between known facts, axioms, and inferences. This functional block is used by all other functional blocks of the ENI system.

Knowledge representation is fundamental to all disciplines of modeling and AI. It also enables machine learning and reasoning — without a formal and consensual representation of knowledge, algorithms cannot define the reasoning about the knowledge (e.g., perform inference, correct errors, and derive new knowledge). Knowledge representation defines mechanisms for the characteristics and behavior of the set of entities being modeled; this enables the computer system to plan actions and determine consequences by reasoning using the knowledge representation, as opposed to taking direct action on the set of entities.

Context-Aware Management Functional Block

The purpose of the Context-Aware Management Functional Block is to describe the state and environment in which an entity exists or has existed. Context consists of measured and inferred knowledge, and may change over time. Context-aware management is used to continuously update the context in which decisions are made.

Context consists of measured and inferred knowledge, and may change over time. For example, a company may have a business rule that prevents any user from accessing the code server unless that user is connected using the company intranet. This business rule is context-dependent, and the system is required to detect the type of connection of a user, and adjust access privileges of that user dynamically.

Situational Awareness Functional Block

ENI defines the situational awareness as the perception of data and behavior that pertain to the relevant circumstances and/or conditions of a system or process ("the situation"), the comprehension of the meaning and significance of these data and behaviors, and how processes, actions, and new situations inferred from these data and processes are likely to evolve in the near future to enable more accurate and fruitful decision making.

The purpose of the Situational Awareness Functional Block is for the ENI system to be aware of events and behavior that are relevant to the environment of the system that it is managing or assisting. This includes the ability to understand how information, events, and recommended commands given by the ENI system will impact the management and operational goals and behavior, both immediately and in the near future. Situational awareness is especially important in environments where the information flow is high, and poor decisions may lead to serious consequences (e.g., violation of SLAs).

Policy-Based Management Functional Block

The purpose of the Policy Management Functional Block is to provide decisions to ensure that the existing system goals and objectives are met. Policies are used to provide scalable and consistent decision making.

There are three different types of policies that are defined for an ENI system.

Imperative policy: A type of policy that uses statements to explicitly change the state of a set of targeted objects. Hence, the order of statements that make up the policy is explicitly defined.

Declarative policy: A type of policy that uses statements to express the goals of the policy, but not how to accomplish those goals. Hence, state is not explicitly manipulated, and the order of statements that make up the policy is irrelevant.

Intent policy: A type of policy that uses statements to express the goals of the policy, but not how to accomplish those goals. Each statement in an intent policy may require the translation of one or more of its terms to a form that another managed functional entity can understand.

An ENI system may use any combination of imperative, declarative, and intent policy to express recommendations and commands to be issued to the system that it is assisting.

Cognition Framework Functional Block

The purpose of the Cognition Framework Functional Block is to enable the ENI system to understand ingested data and information, as well as the context that defines how those data were produced. The cognition framework

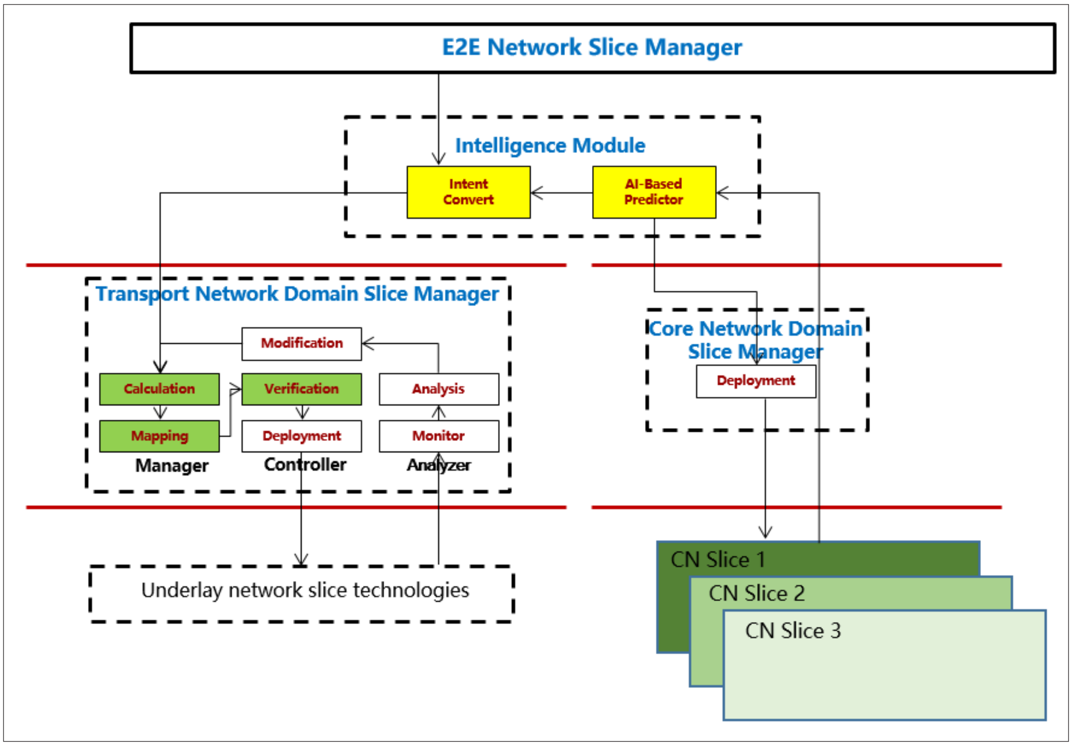

FIGURE 6. An example of ENI PoC on end-to-end network slicing life cycle management

The PoC will address network slicing management, one of the most challenging use cases, where architectural and key technologies innovations provided by ENI are critical. In addition, the new technical challenges on data transmission and network management make AI a competitive option to handle different types of complex network slicing scenarios.

is a collection of functional blocks that relates each of the above four functional blocks to the set of end-to-end goals that the ENI system is given. This means that the scope of the cognitive framework is conceptually operating above the scope of both the infrastructure and the other functional blocks of the ENI system. The cognition framework functional block provides the following functions:

1. Change existing knowledge and/or add new knowledge corresponding to those data and information.
2. Perform inferences about the ingested information and data to generate new knowledge.
3. Use raw data, inferences, and/or historical data to understand what is happening in a particular context, why the data were generated, and which entities could be affected.
4. Determine if any new actions should be taken to ensure that the goals and objectives of the system will be met.

In each of the four functions above, the cognition framework uses existing knowledge to validate and generate new knowledge. This means that new knowledge may be added, and in some cases, existing knowledge may be changed. Hence, the ENI system uses a dynamically changing set of repositories (as opposed to other management systems, which typically use repositories that use fixed content).

A cognition framework is conceptually operating above the scope of both the infrastructure and the other functional blocks of the ENI System. It maintains a set of end-to-end goals, such as routing optimizations, connectivity, security, and trust management, by modifying the elements of the infrastructure and the directives of other functional blocks. It uses multiple diverse processes and technologies, including linguistics, computer science, AI, and formal logic, to analyze existing knowledge and synthesize new knowledge.

The work in ENI architecture is included in [10] and is being developed.

Proof of Concept Framework

Proof of concept is important to validate the technologies developed in ENI. The public demonstration of ENI concepts helps to build commercial awareness of and confidence in the work developed in ENI, as well as to develop a diverse, open ENI ecosystem by integrating components from different players. Results from PoCs may also guide the work in the ENI ISG, related SDOs, and open source communities by providing feedback on network operations and other technical challenges.

The ENI ISG works actively in collaboration with industry and academia to develop PoCs, demonstrating the capabilities of the ENI system to support different use cases, under a PoC framework defined in [10]. A PoC is being discussed with the H2020 SliceNet project [11]. The PoC will address network slicing management, one of the most challenging use cases, where architectural and key technology innovations provided by ENI are critical. In addition, the new technical challenges on data transmission and network management make AI a competitive option to handle different types of complex network slicing scenarios.

ENI is also developing a PoC verifying end-to-end network slicing life cycle management. The PoC is based on a test platform from China Telecom and Huawei. It supports intelligent technologies related to Internet Protocol (IP) network slicing management [13] to demonstrate the support of multiple data plane slicing technologies developed by Huawei.

CN-DSM will create multiple core slices to provide different data processing capabilities to different types of services. TN-DSM will select the optimal combination of underlay network technologies to satisfy the dedicated slice QoS requirements, as well as modify transport network slices dynamically subject to the scale in/out of core slices.

The PoC in [13] encompasses three main modules: transport network domain slice manager (TN-DSM), core network domain slice manager (CN-DSM), and intelligent module. CN-DSM and TN-DSM are responsible for providing the processing, storage, and transmission functions implementation according to the decisions made by the intelligent module. In addition, the end-to-end network slice manager offers a portal interface for the input and output of slices.

CN-DSM will create multiple core slices to provide different data processing capabilities to different types of services. TN-DSM will select the optimal combination of underlay network technologies to satisfy the dedicated slice QoS requirements, as well as modify transport network slices dynamically subject to the scale in/out of core slices.

The intelligent module will be in charge of two tasks:

- Slice scale in/out decision making: By using AI methods, it will analyze current and historical slices traffic, predict traffic trends, decide when and how to scale in/out core slices, and decide the modification of transport network slice requirements. The application of intelligent technologies can be a one-size-fits-all solution suitable to most scenarios.
- Slice-input simplification and intent engine: A simplified and friendly input interface is critical to the potential wide use of a network slice. In the meantime, the detailed parameters for deterministically managing a slice are too complicated for vertical slice tenants, and may change subject to the network status. Therefore, an intent engine must be introduced to convert simplified user inputs to detailed slice management parameters.

Conclusions

A comprehensive review of the work developed in the ENI ISG has been provided in this article, including the use cases, requirements, context-aware gap analysis, system architecture, and PoC. ENI is the first ETSI group that focuses on the standardization and specification of an architecture which uses AI to improve the operator's experience. Interested readers are encouraged to read further on ENI group reports and specifications, provided as references in this article.

References

[1] ETSI press release, "New ETSI Group on Improving Operator Experience Using AI," 21 Feb. 2017; https://goo.gl/zLZZso

[2] ETSI ISG ENI Wiki page; https://eniwiki.etsi.org/index.php?title=Main_Page

[3] D. G. Ullman, "'OO-OO-OO!' The Sound of a Broken OODA Loop." *CrossTalk — J. Defense Software Engineering*, 2007, pp. 22–25.

[4] ETSI GR ENI 001 V1.1.1, "Experiential Networked Intelligence (ENI); ENI Use Cases"; http://www.etsi.org/deliver/etsi_gr/ENI/001_099/001/01.01.01_60/gr_ENI001v010101p.pdf

[5] ETSI GS ENI 002 V1.1.1: "Experiential Networked Intelligence (ENI); Requirements"; http://www.etsi.org/deliver/etsi_gs/ENI/001_099/002/01.01.01_60/gs_ENI002v010101p.pdf

[6] A. Dey, *Providing Architectural Support for Building Context-Aware Applications*, Ph.D. thesis, 2000.

[7] J. Strassner *et al.*, "The Design of a Novel Context-Aware Policy Model to Support Machine-Based Learning and Reasoning", *J. Cluster Computing*, vol 12, issue 1, Mar. 2009, pp. 17–43.

[8] J. Strassner, Ed., "MEF Technical Specification: Policy-Driven Orchestration," v. 0.7, Aug. 2017.

[9] ETSI GR ENI 003 V1.1.1, "Experiential Networked Intelligence (ENI); Context-Aware Policy Modelling Gap Analysis"; https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=52852

[10] ETSI GS ENI 005, "Experiential Networked Intelligence (ENI); System Architecture"; https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=54085

[11] H2020 SliceNet Project Website; https://slicenet.eu/

[12] ETSI GR ENI 006, "Experiential Networked Intelligence (ENI); PoC framework"; https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=54509

[13] NGMN Alliance, "Description of Network Slicing Concept," v. 1.0, Jan. 13, 2016; https://www.ngmn.org/fileadmin/user_upload/160113_Network_Slicing_v1_0.pdf

Biographies

Yue Wang [SM] is a principal 5G researcher at Samsung Electronics R&D Institute UK. At Samsung, she works on a variety of technical subjects in the research and innovation of 5G RAN and networks, including leading the collaborative research of 19 partners in the H2020 mmMAGIC project. More recently, her work has been focused on AI in 5G and beyond. She is the Samsung delegate of ETSI ISG ENI, and the Secretary and Rapporteur of ENI. She also sits in the Industry Advisory Board of King's College of London and the University of Sussex, and is the industry supervisor of a five-year research program on AI in 5G. Prior to joining Samsung, she held various roles in the United States and the United Kingdom, and completed her Ph.D. in Canada, all on wireless communications. She is a named inventor of over 30 patents (and patent applications).

Ray C. Forbes was educated at Loughborough University of Technology between 1977 and 1984. He joined Plessey Telecommunications where he worked on software engineering and analysis. Since 1990 he has worked on network development in the area of intelligent networks and the standardization thereof. He has chaired the NGN Protocols in ETSI including the IMS adaptation to fixed networks and the Common IMS programme. He was elected as ETSI TC M2M Protocols WG Chairman. Also, he has been actively involved in the ITU-T Smart Focus Group. He was appointed as Chairman of the M2M Protocols activity in oneM2M the global Standards Partnership Project. Also, he was appointed as Leader of M2M Service Enablement & Utilities Standardization in LM Ericsson. Currently, he is working for Huawei Technologies to lead and chair the ETSI ISG ENI.

Chris Cavigioli was recruited by Intel in 2008 as a strategy planner to define future video, graphics, audio, and IMS/web telecom requirements for Atom-based smartphone platforms. In 2016, he moved to Intel's Data Center Group to tackle edge computing and long-term network strategy planning. He is now focused on Intel's adjacent technologies such as 3D XPoint™ memory and silicon photonics in 5G, AI, networking, telecom, and visual cloud markets. For several decades, he has enjoyed the cutting edge of wireless telecom and multimedia innovation, connecting product definitions with the technopolitics of standards in 3GPP, ETSI, MPEG, ITU, and GSMA. These decades span over 12 years at Analog Devices doing DSP applications in Boston, then GSM chipsets in Munich. At Synopsys, he helped launch SystemC and system-level design tools ,and ran business development for Asia-Pacific for those products. He ran marketing for NemeriX, a fabless startup based in Switzerland, building the world's lowest-power GPS chipset. At MIPS Technologies, he did IP licensing for processor cores and third-party multimedia IP engines. He has an engineering degree from Worcester Polytechnic Institute in Massachusetts and did his junior year abroad at ETH, Zurich, Switzerland. He speaks five languages and is passionate about turning futuristic dreams into commercial products.

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