DAEMON: A Network Intelligence Plane for 6G Networks

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***Abstract*—While there is a clear trend towards network automation through the usage of Artificial Intelligence (AI) and Machine Learning (ML) solutions, the major reference network architectures are still not natively including all the mechanisms needed to handle Network Intelligence (NI). This paper introduces a novel architecture proposed within the EU-funded DAEMON project, which includes a Network Intelligence Plane (NIP) that natively integrates NI into the network operation, management, and orchestration procedures. We do so by analyzing the gaps in current reference architectures and designing a Network Intelligence Orchestration (NIO) that handles the most important NI-related mechanisms such as lifecycle management, coordination, and data management.**

***Index Terms*—6G, Mobile Networks, Network Intelligence, Network Intelligence Function, Network Intelligence Plane, Network Intelligence Service, Orchestration.**

I. Introduction

Thanks to the recent advances in Artificial Intelligence (AI)/Machine Learning (ML), 6G networks will be fully autonomous. How to allow the capabilities of, e.g., re-orchestrating, auto-scaling, and self-organizing are discussion topics of major Standard-Defining Organizations (SDOs) such as 3GPP and European Telecommunications Standards Institute (ETSI), as well as Industrial organizations such as O-RAN. Starting from the initial definition of the Network Data Analytics Function (NWDAF) reference point in the early releases of 3GPP Rel. 15 [1], there has been a continuously growing interest in how to enable the intelligent operation of the network. This interest is also driven by the increased complexity of a mobile network's operation, management, and orchestration compared with the legacy versions.

Orchestrating micro-services based and cloud native Network Function (NF), over heterogeneous resources (that also encompass far-edge infrastructure deployments), with a set of different services related to many providers, and with new requirements (such as energy sustainability) impose a totally different way to perform operations that were formerly performed purely through human intervention or ruled-based systems. As the main enabler of the autonomous network operation is data, the first effort for enabling this view is in the overall architecture principally targeting these aspects, defining procedures, elements, and interfaces for the efficient data gathering and its publishing through codified analytics.

While indeed data is a fundamental aspect that has to be taken into account, there are other ones that shall also be addressed, such as the openness of the analytics across network domains [2] or the definition of an ontology for the intelligence algorithms [3]. In this paper we present a novel Network Intelligence Plane (NIP), developed within the context of the EU-funded DAEMON project [4], and to be included in the traditional control and user plane network functions already envisioned by, e.g., 3GPP systems. Motivated by the need for an entirely new way of handling the lifecycle of Network Intelligence Functions (NIFs) that assist the operation of c- and u-plane functions, empowering them with intelligence, we propose a set of new modules, interfaces, and procedures that natively introduce intelligence into the network architecture.

The remainder of this paper is organized as follows: in Sec. II, we discuss and identify the gaps present in the current reference architectures of major SDOs regarding the introduction of intelligence in the network. Then, in Sec. III, we discuss the DAEMON architecture for the NIP. Then in Sec. IV, we discuss the internals of the major component in our architecture: the Network Intelligence Orchestration (NIO). Finally, we conclude the paper in Sec. V.

II. Gaps and Requirements for Network Intelligence (NI) Orchestration

Beyond 5G (B5G) and 6G networks set forth a vision for end-to-end NI coordination aimed at ensuring a conflict-free and synergic operation of the many NI algorithms running across schedulers, controllers, and orchestrators in the network [3], [5]. As a first step in the rigorous design of a complete framework for the joint operation of NI instances, we have identified a set of gaps in the current frameworks for mobile network management that the main Standard-Defining Organizations (SDOs) propose.

In general, we found out (see Section 5 and Appendix B of [6] for more details) that current standards and platforms proposed by the European Telecommunications Standards Institute (ETSI), O-RAN, or 3GPP, as well as implementations of the same institutions like Open Source MANO (OSM) or Open Network Automation Platform (ONAP) do not provide (i) mechanisms to coordinate intelligence across different network micro-domains, or (ii) solutions for decentralized and unified data management across NI instances. Also, their (iii)

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support for managing the NI lifecycle is minimal, and there is only an early consideration for (iv) methodologies for the defining and representing of NI models. Table I summarizes the functionalities for NI management supported by the existing frameworks for end-to-end NI control and orchestration in mobile networks.

To tackle the gaps mentioned above and remove the current barriers to fully support the aspects not necessarily covered by existing frameworks, in this paper, we outline a clear set of functional and non-functional requirements, targeting the coordination of NI instances in an end-to-end fashion. We name the framework for such coordination the Network Intelligence Plane (NIP), as we conceive it as a novel plane in the mobile network, complementing those already existing in 5G architectures, i.e., the user or data plane, the control plane, and the management plane. The NIP requirements tree is organized into five major branches in terms of Functional Requirements (FR) and two major branches in terms of Non-Functional Requirements (NFR). Below is a brief description of these branches; however, a full description of the complete NIP requirement tree is provided in [7].

The NIP shall orchestrate NI. The first branch of NIP requirements concerns the capability of the NIP to decompose complex NI instances and represent them as a combination of atomic NI elements. This decomposition is a paramount requirement for the NIP to have the fine-grained control necessary to orchestrate all network-wide NI-related operations by handling closed control-loop in different micro-domains. This paper defines complex NI instances as Network Intelligence Service (NIS) composed of multiple atomic Network Intelligence Functions (NIFs). We will later provide formal definitions of the NIS and NIF concepts in Section III. The NI orchestration's ultimate goal is the ability to create when needed and in an automated manner, an end-to-end NIS that can achieve specific Key Performance Indicators (KPIs) and meet business needs.

The NIP shall provide NI Interfaces to enable communication between NI instances and the Network Intelligence Orchestration (NIO). The second branch of NIP requirements assumes the appropriate interfaces to allow the necessary communication among the different building blocks of the NIP and existing external elements. For instance, when a NIS is created/composed, training the NIFs that constitute the NIS calls for deploying ML Operations (MLOps) frameworks, for which several commercial solutions exist. Similarly, NISs are deployed within network controllers or orchestrators managed by traditional Management and Orchestration (MANO) frameworks, making interactions of the NIP with those mandatory. Reinventing such MLOps or MANO frameworks is not a sensible choice. Instead, developing the required interfaces between the NIP and such existing frameworks makes the proposed solution in this paper more appealing since it favors its fast integration into existing industry initiatives. Thus, these interfaces shall also comply with relevant current standardization efforts, e.g., by 3GPP, O-RAN, or ETSI.

The NIP shall manage NI. The third branch of NIP requirements expects the NI plane to manage the complete lifecycle of both NIS and NIF. Specifically, once a NIS is released for production, the NIP shall support its onboarding, instantiation, termination, scaling, and state retrieval. The same should happen with the different NIFs that compose each NIS. In the context of NI instances, its lifecycle management also includes monitoring the NI's health. The monitoring comprises specific diagnostic information, such as the NI operation mode (e.g., inference or training), the NI type (e.g., online, supervised, unsupervised, or reinforcement learning), and the NI performance metrics (e.g., loss, accuracy), among others. Moreover, the NIP needs to provide feedback on the NI performance so that higher-level decisions can be made (e.g., about the need for the model to be updated or replaced).

The NIP shall provide NI coordination. The fourth branch of NIP requirements defines the preconditions about the capability of the NIP to perform conflict resolution and guarantee the overall stability of NI instance operation in an end-to-end fashion, possibly taking advantage of synergies across NI. Coordination of NI can include, but is not limited to, (i) sharing measurement and input data among different NIFs, (ii) arbitration policies in case of two NIFs share the same sink, that is, the configuration Application Programming Interfaces (APIs), or (iii) control of system stability among conflicting policies, actions or decisions, e.g., when optimizing a particular objective function at one network domain may be counterproductive to equivalent processed in other domains, hence jeopardizing end-to-end stability of the automated network management.

The NIP shall provide NI catalogs. The fifth and final branch of NIP requirements defines the need for the NIP to be able to access catalogs of both NIS and NIF, which have already been onboarded and feature varied performance and complexity for the same specific network functionality. These catalogs are paramount for the NIP to make informed choices about the most appropriate NIS or NIF to instantiate at a given time and in a specific controller or orchestrator, based on, e.g., available computing resources, inference latency requirements, or accuracy constraints.

As far as NFRs are concerned, the two main specifications for the NIP are as follows:

The NIP will support multiple virtualization environments. Mobile network infrastructures are characterized by a variety of virtualization environments across micro-domains. As a basic example, resource-limited edge platforms employ different virtualization techniques than large and resourceful core network datacenters. Consequently, the NIP should support heterogeneous virtualization environments for deploying services/applications in distributed domains, providing specific maintenance and virtualization-specific policies for orchestration operations.

The NIP will support federated multi-domain management. Due to the high mobility of users in mobile ecosystems, applications are deployed in a distributed way across different edge platforms. Thus, the NI-assisted management and orchestration provided by the NIP should support cross-domain/cross-edge service orchestration for achieving seamless service operation.

TABLE I: Main gaps in SDOs and networking-related frameworks with respect to NI functionalities

Framework	Methodology to define NI	Mechanisms to manage lifecycle of NI	Mechanisms to coordinate NI across different network segments	Decentralized and unified data management for NI instances
ETSI MEC	No	No	No	No
ETSI NFV	No	No	No	No
ETSI ENI	Yes	No	No	No
O-RAN	Yes	Partially	No	No
OSM	No	No	No	No
3GPP	No	No	No	No
ONAP	No	No	No	No
NIP (this paper)	Yes	Yes	Yes	Yes

Management-level agreements are necessary for establishing collaboration between orchestration and management entities and NIFs in different (e.g., edge) domains.

Note that the requirements above, both functional and non-functional, concern the NIP, which optimizes the operation of NI instances across all mobile network architectural (micro-)domains. A NI instance could handle a given networking functionality; hence, each should target one or more network KPIs. Since the NIP requirements are orthogonal to the functioning of each NI instance, such requirements can be seen as enablers concerning all KPIs targeted by NI functionalities. Therefore, the NI architectural framework that fulfills common tasks related to NI management could be easily streamlined in the network. For a detailed description of FR and NFR for several NI functionalities, we refer the reader to [7].

III. Architectural design of a Network Intelligence Plane (NIP)

This section presents the initial design for an architectural model developed by the DAEMON project [4]. The design stems from and integrates with current standards (e.g., O-RAN, 3GPP, ETSI) and realizes the vision of native support for end-to-end Network Intelligence (NI) orchestration. We recall that the NI-native architecture is expected to bring together a variety of NI-assisted functionalities that span different timescales and network domains in a coordinated manner. To achieve this result, our design builds upon and adheres to the functional and non-functional requirements laid down in Section II.

A. NIP architecture

Owing to the softwarization and the data-driven trends of current networks, we decompose the structure into four complementary layers: in addition to the legacy infrastructure layer, the control plane, and the user plane (which are the three fundamental building blocks of a software network such as the 5G one), in this paper, we envision one additional layer, the NIP, that integrates the functions related to NI. Figure 1 describes the overall framework where the envisioned NIP will run and interact.

Two modules perform the Management and Orchestration (MANO) of this compound network: the MANO, as traditionally done in 5G Networks, which handles the typical lifecycle management of the network and Virtual Network Functions (VNFs), and a new sibling element, the Network Intelligence

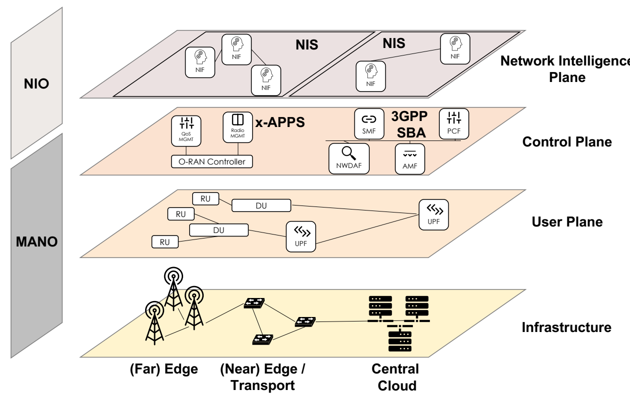

Fig. 1: A NI framework for 6G networks

Orchestration (NIO) (described in Section IV), which takes care of all the operations related to the management of the intelligence of the network (represented by a variety of NI instances deployed across micro-domains). These operations include:

1) The selection of the appropriate Network Intelligence Function (NIF) that come together to build a Network Intelligence Service (NIS) to pursue the Key Performance Indicators (KPIs) envisioned by each functionality.
2) The monitoring of the NI's health, including tracking their performance metrics (e.g., their accuracy) and the specific actions that may be taken to optimize them (e.g., meta parameter change, re-training, or model changes).
3) The specific training procedures in the case of learning models.
4) The interaction with the MANO to handle service and resource orchestration.

For MANO, we reuse all ETSI's definitions and functional components [8]. We omit these to avoid clutter, and we refer to [8] for a detailed explanation of such terminology. Instead, we focus on discussing in detail and defining the internals of the novel NI orchestration, which is part of the NIP, specifying interfaces and procedures.

In this paper, we envision the management of NI in a similar manner as the management of Network Service (NS) is designed for 5G Networks. This allows us to reuse well-known concepts, adapting them to the context of network intelligence. Following this strategy, and analogously to the information model specified for network management by, for

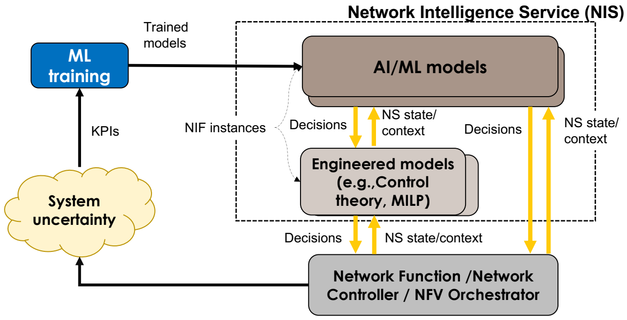

Fig. 2: Taxonomy of NIP operations

instance, 3GPP, we define the concepts of NIS (cf. NS, i.e., a 5G service class such as Enhanced Mobile Broadband (eMBB) or Ultra-Reliable Low Latency Communications (URLLC)) and NIF (like any function specified by, e.g., 3GPP or O-RAN), as follows.

NIF: Functional block in a NI that implements a decision-making functionality to be deployed in a controller, Network Function Virtualization (NFV) orchestrator, or Network Function (NF) with well-defined interfaces and behavior. A NIF thus corresponds to an individual NI instance (e.g., the implementation of the algorithms detailed in Table II) that assists a specific functionality.

NIS: Composition of NIFs with a specific target, usually related to a particular set of targeted KPIs. Table II shows examples of NISs derived from NI functionalities developed in the project DAEMON[1] and described in detail in [9], [10].

There is a one-to-many relationship between NIS and NIFs, as the former could be provided by one or more instances of the latter. Consequently, network operators or service providers can, for example, request specific sustainability and reliability services targeting one or more KPIs. The NIO will take care of providing such service by composing specific instances of NIFs.

NIFs themselves could be of different kinds: they could be learning models based on, e.g., Deep Neural Networks (DNNs) or Engineered Models, or they could be built upon specific optimization algorithms such as the ones based on control theory or Mixed-Integer Linear Programming (MILP). The heterogeneous definition of NIFs is fully aligned with the vision of the DAEMON project of NI as the result of algorithms that are not limited to complex Artificial Intelligence (AI) models but also encompass traditional and interpretable models that are not necessarily data-driven.

The high-level interactions among the building blocks mentioned above are depicted in Figure 2. The NIFs have two main interactions with the underlying layers (c-plane, u-plane, or infrastructure, proxied by an NFV Orchestrator). As a matter of fact, NIFs both (a) inject decisions and (b) receive information about the Network Slice State (NSS) and the context of such state. Hence a NIS is a coordinated effort of one or more NIFs that could be arranged hierarchically. For example, a NIS could be composed of a Learning-type NIF

[1]https://h2020daemon.eu/

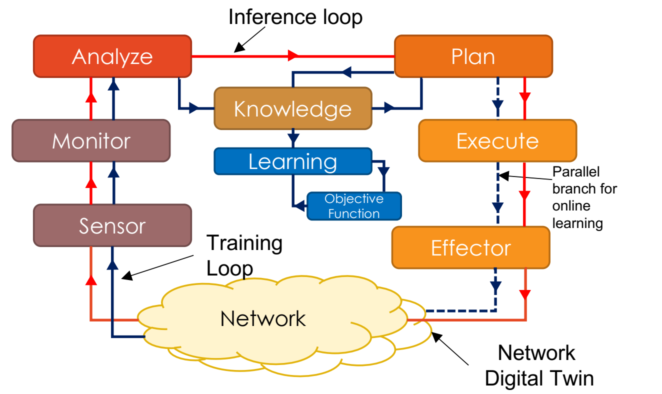

Fig. 3: Extended N-MAPE-K abstractions for NI algorithms

sending decisions to an engineered model NIF, which acts on the underlying infrastructure.

B. NIF representation framework

To manage the interaction between different NIFs, we have defined an additional level of detail that decomposes each NIF into atomic elements that perform a specific operation. Besides the specific requirements associated with the algorithms (Section 2, [7]), we need a mechanism to create a common framework to map the most common features of NI algorithms, subsequently integrate them into the overall architecture, and design the necessary interfaces that algorithms use to interact with their environment.

For this purpose, we adopt a methodology already used by the Monitor-Analyze-Plan-Execute over a shared Knowledge (MAPE-K) feedback loop—one of the most influential reference control models for autonomous and self-adaptive systems [11]. This nomenclature adopted to label NI requirements within DAEMON was first introduced in [5], and it allows for classifying the algorithms that run at NI instances in a unified manner, based on how they interact with the other elements of the network.

It is worth noting that the original MAPE-K framework has limitations in the context of mobile network functionalities supported by NI, which is our target in the project. To overcome such limitations, we propose changes to the legacy MAPE-K to consider the specificities of the network environment, as depicted in Figure 3. In this figure, we illustrate the different training and control loops that a NIF may implement: (i) the inference loop, (ii) the training loop, and (iii) a different training loop with a branch for online learning. The model emerging from this adaptation is coined the Network Monitor-Analyze-Plan-Execute over a shared Knowledge (N-MAPE-K).

The extensions of N-MAPE-K over the original MAPE-K concern, in particular, the following two dimensions.

1) The purpose of the NIF, i.e., whether the Knowledge is (a) being trained or (b) being used for inference during the operation of the network, following the ML Operations (MLOps) paradigm.
2) The nature of the NIF algorithm, i.e., telling apart online learning or pre-trained/engineered models.

TABLE II: Examples of several NISs, their NIFs, and their associated KPIs

NIS	KPIs	NIFs
Reliable Virtualized RAN	Reliability	Reliable distributed unit (DU) for virtualized RAN
		Orchestration of radio and computing resources in vRANs
Sustainable network operation	VNF Energy Savings	Cloud Acceleration for virtualized RAN
		Compute Aware scheduling analytics
		AI-enhanced edge orchestration
	Compute Resource Savings	Data-driven resource orchestration
	OPEX Savings	Multi-timescale network slice reservation
Network capacity management	Wireless Capacity Increase	Reconfigurable Intelligent Surfaces Control
Edge orchestration	OPEX Savings	Network Service Auto-scaling
		Capacity forecasting

For the latter, the Knowledge module shall be integrated with a training definition, which contains all the algorithm attributes and specifies aspects such as the input data format, training batches, and training epochs. Most importantly, consistently with the NI design guidelines set forth by DAEMON (see [5]), the training shall specify the used loss function (which could be dynamically adjusted) and the State/Action representation –depending on whether the NIF algorithm belongs to the family of supervised learning models or to one of online learning ones. Additionally, the Effector and the Sensors can be redirected to a Digital Twin element, if needed by the specific NI instance, to disentangle the learning-loop process from the actual operation of the network.

Based on the resulting N-MAPE-K representation adopted by the DAEMON project, each NIF can be further split into atomic NIF Components (NIF-C) as follows.

The **Sensors** block specifies all the probes needed to gather the input data and its kind, e.g., images, values, sequences, etc. In principle, Sensors within the NIF correspond to the Application Programming Interfaces (APIs) used to interact with the software and hardware measurement probes and data repositories deployed in the network infrastructure.

The **Monitor** block specifies how the NIF interacts with the Sensors, i.e., when and how it accesses the APIs mentioned above.

The **Analyze** block includes any pre-processing, summary, or preparation of the data, such as those implemented by averaging, autoencoding, or clustering algorithms.

The **Plan** block constitutes the specific NI algorithm implemented by the NIF, for instance, a Neural Network (NN) performing a classification task.

The **Execute** block specifies how the algorithm is going to interact with the system and how to possibly change its configuration parameters.

Finally, the **Effector** block includes specific configuration parameters updated in the Network Function, specifying the **API** to be used to that end.

In our previous paper [3], we showed how the N-MAPE-K framework could be leveraged to model, in a unified way, two algorithms for Radio Access Network virtualization (vRAN) orchestration, enabling their joint NI operation and lifecycle management. These algorithms were developed within the DAEMON project and presented in [12]–[14].

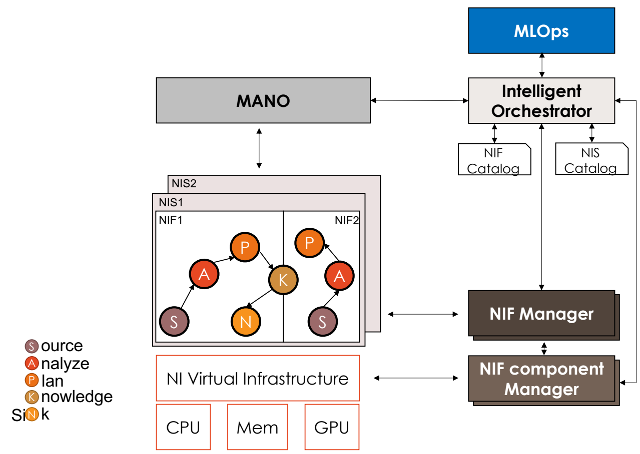

Fig. 4: Architecture of the NIO

IV. Network Intelligence Orchestration (NIO)

We now detail the structure of the proposed NIO, which is designed to fulfill the Network Intelligence (NI) management and coordination requirements outlined in Section II.

To manage and orchestrate the Network Intelligence Service (NIS), Network Intelligence Function (NIF), and NIF-C that build the NI, we mutated the layered structure of the ETSI NFV MANO framework, tailoring the components to the specificities of NI. The resulting NIO framework, depicted in Figure 4, is organized into three levels, i.e., (i) the Intelligence Orchestrator (IO), (ii) the NIF Manager, and (iii) the NIF-C Manager. We next detail the functions and operation of these three levels.

***NIF Component Manager*:** This component is in charge of handling the lifecycle of the NIF-C. By lifecycle management, we refer to operations that include onboarding, instantiation, termination, scaling, and state retrieval. All these are handled by the NIF-C Manager independently of their kind (i.e., independently of whether they are Source / Analyze / Plan / Knowledge / Sink) and their connection to the Infrastructure. For instance, in the case of Sources, the IP addresses of the different data producers shall be provided. In contrast, in the case of Sinks, the specific configuration API endpoints have to be configured. This will have specific instantiations according to where this interaction shall take place. For instance, if the NIF is executed from the core, then Sinks and Sources shall integrate with the Network Registry Function (NRF) and the Network Exposure Function, properly synchronizing with the Network Data Analytics Function (NWDAF) [15], whose analytics are captured as a set of Analyze, Plan, and Knowledge boxes. Similar considerations also apply to other network domains, such as the Radio Access Network (RAN), where this framework can be fully integrated with the O-RAN x-Apps or r-Apps ecosystems [16].

***NIF Manager*:** The NIF Manager, instead, has a global view of the set of NIF-C that compose every NIF. Besides the lifecycle management of the NIF, this module is in charge of monitoring the health of the intelligence functions. The monitoring considers the permanent tracking of Key Performance Indicators (KPIs) yielded by the NIFs, such as its accuracy, if the NIF is being used in inference or it is an online learning solution; other metrics would be monitored, such as the loss and the training loops, in case the NIF is currently being trained. The NIF Manager is also responsible for setting the meta-parameters of the models (through the interaction with the NIF-C manager) and reporting the health status of the NIF to the upmost module in the hierarchy, i.e., the IO.

IO: This module is in charge of the lifecycle management of the NIS by properly coordinating the NIFs that build each of them. This includes the possibility of sharing NIF-C among different NIFs (e.g., two NIFs that require the same input) and also the arbitration policies in the case of two NIFs that share the same sink, that is, the configuration Application Programming Interfaces (APIs). Note that this is performed at the level of the IO, and it is no longer the responsibility of the NIF Manager. Indeed, this coordination is not within a single NIF (which is a task for the NIF Manager) but across NIFs, hence requiring a higher-level view that only the IO has. This module also manages the connections towards the network management and orchestration to gather important information, such as the expected network KPIs for the managed slice and service and the status of the underlying network infrastructure. The IO has catalogs of already onboarded NIS and NIFs. In particular, NIFs may need to be re-trained to cope with changing or different conditions, or on a periodical basis. In this case, the IO interfaces with an external platform to build ML pipelines and perform such operations (e.g., an ML Operations (MLOps) framework).

V. Conclusions and Future Work

This paper presented a Network Intelligence Plane (NIP), a novel architectural component for 6G envisioned within the DAEMON project. The NIP natively integrates Network Intelligence (NI) into the network operation, management, and orchestration procedures of mobile networks, complementing those already existing in 5G architectures, i.e., the user or data plane, the control plane, and the management plane. The NIP provides (i) the mechanisms to coordinate intelligence across different network micro-domains, (ii) a solution for decentralized and unified data management across NI instances, (iii) the support for the management of the NI lifecycle, and (iv) a methodology for the definition and representation of NI models. As future work, we will continue the evolution of the proposed architecture and validate it via proof of the concept.

Acknowledgment

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