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Unifying 3GPP, ETSI, and O-RAN SMO Interfaces: Enabling Slice Subnets Interoperability

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***Abstract*—This article addresses two architectural challenges associated with managing and orchestrating open radio access network (O-RAN) slice subnets within the service management and orchestration (SMO) Framework. The first challenge involves unifying the components and interfaces of the O-RAN Alliance, Third Generation Partnership Project (3GPP), and European Telecommunications Standards Institute (ETSI) to enhance the capabilities of the SMO Framework regarding the management and orchestration (M&O) of O-RAN slice subnets and their required resources. The objective of this unification is to eliminate ambiguity in the interaction, interworking, and integration of various standards within a unified SMO Framework and to enable it to leverage the latest specifications. The second challenge entails facilitating standard-compliant interoperability among the components of the three modules by proposing two logical functions and their interfaces within the SMO Framework. This interoperability is intended to enable the components and interfaces of the O-RAN architecture to influence the decisions made by the 3GPP and ETSI components and interfaces concerning O-RAN slice subnets. It will also allow the 3GPP and ETSI components and interfaces to improve their capabilities by utilizing the features and services of the O-RAN architecture.**

***Index Terms*—Management & Orchestration, Network Slicing, O-RAN Architecture, O-RAN Slice, SMO Framework, Standards**

I. Introductory Remarks

THE M&O of O-RAN network slice subnets (NSSs), hereinafter referred to as O-RAN slices, in O-RAN architecture are challenging due to their heterogeneous operator- and tenant-specific requirements, the integration complexity of components and systems of various standards developing organizations (SDOs), and the growing multiplicity of parameters that must be defined and configured to acquire optimality. To address these challenges, the O-RAN Alliance specified the SMO Framework [1], which is in charge of intelligently managing and optimizing a large number of O-RAN slices, autonomously orchestrating their required virtual and physical resources, and supporting the fault, configuration, accounting, performance, security (FCAPS) of the O-RAN slice components via a number of open and standardized interfaces. Figure 1 illustrates that the Non-Real-Time RAN intelligence controller (Non-RT RIC) is a crucial component of the SMO Framework [2] that controls the content carried over the A1 interface and operates on a control loop with a time scale of $>= 1$ second. It consists primarily of the Non-RT RIC Framework and its Applications (rApps). The former provides functionality that terminates the A1 interface, enables the rApps to expose the SMO services via the R1 interface, and manages artificial intelligence (AI) and/or machine learning (ML) workflows to run the rApps [2]. The latter provides value-added services related to the operations of the O-RAN architecture by leveraging the functionality exposed by the Non-RT RIC (or SMO Framework) and subsequently applying such services over the O1, O2, and O-FH M-Plane interfaces, thereby enabling the Non-RT intelligent control and optimization of O-RAN slices and their resources, as well as providing policy-based guidance to the Non-RT RIC [2].

To embed the novel capabilities and features of the Non-RT RIC into the elements of an O-RAN slice, the O-RAN Alliance specified the Near-Real-Time RAN intelligence controller (Near-RT RIC), which is deployed at the edge of a cellular network and connected with each element of an O-RAN slice via a southbound interface (i.e., E2) [1], [2]. It allows Near-RT autonomous control and intelligent optimization (in a control loop with a periodicity $>= 10$ miliseconds and < 1 second) of the O-RAN slice elements by employing fine-grained data collection methods and actions over the E2 interface, as well as managing their AI/ML workflows. Figure 1 illustrates that it terminates three open interfaces, includes Near-RT RIC Applications (xApps), and consists of components (such as conflict mitigation, subscription management, security, etc.) that support the execution of xApps [1].

Both RICs deploy the non- and near-RT policies and control actions atop 3GPP-defined open next generation node B (O-gNB), which according to Split Option 7.2x can be split into open centralized unit (O-CU), open distributed unit (O-DU), and open radio unit (O-RU) [1], [3]. The O-CU implements the higher layer radio functionalities and can be further split into two components: the control plane (CP) and the user plane (UP). The O-DU deploys the lower layer radio functionalities. The O-RU accommodates the physical layer functionalities and is hosted by a cellular site. The O-CU and O-DU, which terminate E2 interfaces, support a real-time control loop that operates in a timeframe of < 10 miliseconds [1]. The E2 nodes can be deployed on the open-cloud (O-Cloud), which is a cloud platform consisting of virtual/physical resources that host the components of an O-gNB, the Near-RT RIC, the supporting software components, and other M&O functions. The O-Cloud sites are distributed geographically across the cloud infrastructure and are connected among each other and with cellular sites via highly reliable and high-capacity open-backhaul (O-BH), open-midhaul (O-MH), and open-fronthaul (O-FH) transport links, respectively [3].

Notwithstanding the O-RAN components and interfaces, the SMO Framework must support M&O components of ETSI Industry Specification Groups (ISG) on Network Function Virtualization (NFV) and 3GPP Technical Specification Group (TSG) Service and System Aspects Working Group 5 (SA5) to

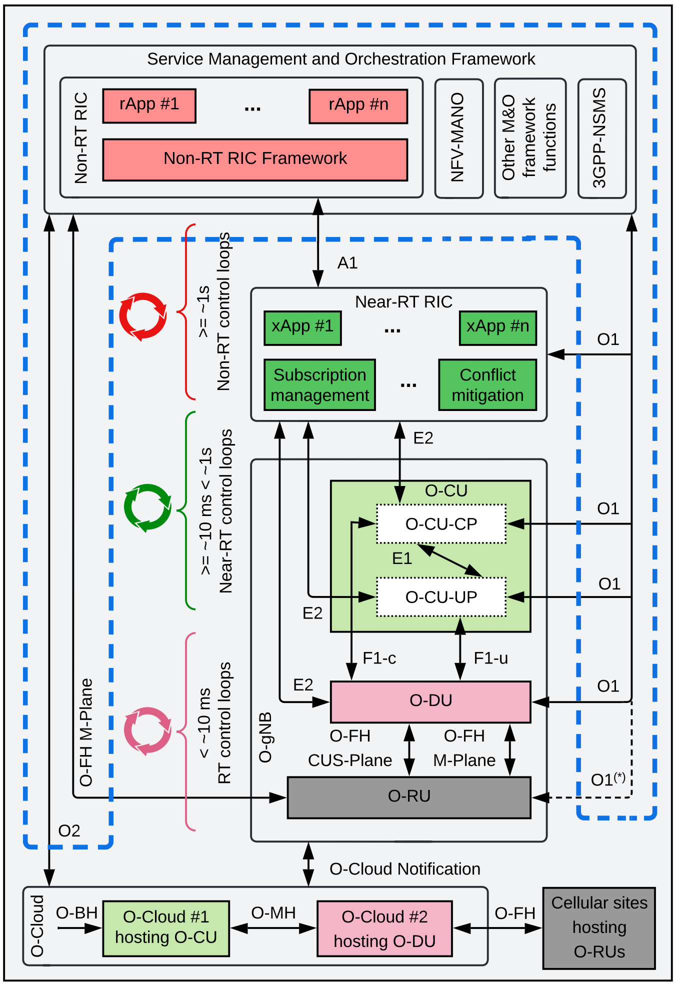

Fig. 1. O-RAN slicing-aware architecture. This article addresses topics within the boundaries of the dashed blue box. (*) The O-RU termination of the O1 interface towards the SMO Framework is a subject for future study.

facilitate end-to-end (E2E) M&O for O-RAN slices. We refer to the specifications of the two SDOs as NFV-management and orchestration (NFV-MANO) and 3GPP-network slicing management system (3GPP-NSMS), respectively. **To realize a unified SMO Framework, interoperability among the Non-RT RIC, NFV-MANO, and 3GPP-NSMS is a prerequisite.** Although the O-RAN Alliance presented multiple deployment options for the components of the NFV-MANO and 3GPP-NSMS within the SMO Framework [1], **the corresponding technical report does not provide sufficient detail on how these components can be tightly integrated, smoothly unified, and made to interwork seamlessly for the effective implementation of O-RAN slicing.** Furthermore, at the time of writing this article, **the O-RAN Alliance had not yet defined the functions and interfaces required to achieve interoperability among these modules.**

To address the research challenges described above, we propose the following contributions:

- First, we clarify ambiguity regarding the interworking and interaction between the Non-RT RIC, NFV-MANO, and 3GPP-NSMS by designing a unified architecture for the SMO Framework, thereby enabling the Near-RT RIC, the O-gNB network functions (NFs), and the O-RAN interfaces to support slicing-aware and slice-dedicated xApps and rApps features and capabilities.
- Second, we propose two functions for the Non-RT RIC and interfaces between the Non-RT RIC, 3GPP-NSMS, and NFV-MANO within the SMO Framework. The goal is to facilitate standard-compliant interoperability among these modules, allowing the Non-RT RIC to influence the O1, O2, and O-FH M-Plane interfaces and enabling the NFV-MANO and 3GPP-NSMS to access the rApps and Non-RT RIC services.

The rest of this article is organized as follows. We begin by discussing the unification of the three modules and the design of a unified SMO Framework. Then we describe the proposed functions and interfaces and their potential contributions to the O-RAN architecture. Finally, we summarize the article by drawing conclusions and outlining future research directions.

II. Unifying 3GPP-NSMS, NFV-MANO, and Non-RT RIC for O-RAN Slicing within the SMO Framework

The SMO Framework can consist of the 3GPP-NSMS, the NFV-MANO, and the Non-RT RIC. In this section, we discuss and unify these modules to design a unified and standard-compliant framework for the M&O of O-RAN slices.

A. 3GPP-NSMS for O-RAN Slicing

The 3GPP-NSMS within the SMO Framework includes network slice management function (NSMF), network slice subnet management function (NSSMF), and network function management function (NFMF), as shown in part (❶) of Figure 2. These entities are linked via 3GPP-defined interfaces [3]. The NSMF manages an E2E network slice (NS) using a customized network slice template (NST). To date, the 3GPP has specified five slice/service types (SSTs), each of which identifies the service type of an NS [4]. They are enhanced mobile broadband (eMBB), ultra reliable and low latency communications (URLLC), massive machine type communications (mMTC), vehicle-to-everything (V2X), and high-performance machine type communications (HMTC) [3]. Each NS has an SST value of $1-5$, respectively. The NSSMF manages a subnet of an E2E NS. In the O-RAN architecture, it manages the FCAPS of an O-gNB that participates in O-RAN slicing. The NSSMF also translates the requirements of an O-RAN slice into the quantity of virtual, physical, cloud, and/or radio resources that must be allocated to the respective O-RAN slice using a customized network slice subnet template (NSST). The NFMF is responsible, from an application standpoint, for the FCAPS of a particular type of O-gNB NF via the O1 interface, which is analogous to the Itf-S interface in [3]. It expressly denotes the existence of separate NFMFs for the O-CU, O-DU, and O-RU in an O-RAN slice. The Near-RT RIC is a logical NF; hence, its FCAPS can also be managed by a NFMF.

The O-RU is the physical network function (PNF). There are three scenarios for managing an O-RU (see Figures 1 and 2): (i) the O-DU manages the O-RU via the O-FH M-Plane interface; (ii) the SMO Framework controls the O-RU via the O-FH M-Plane interface; and (iii) the SMO Framework

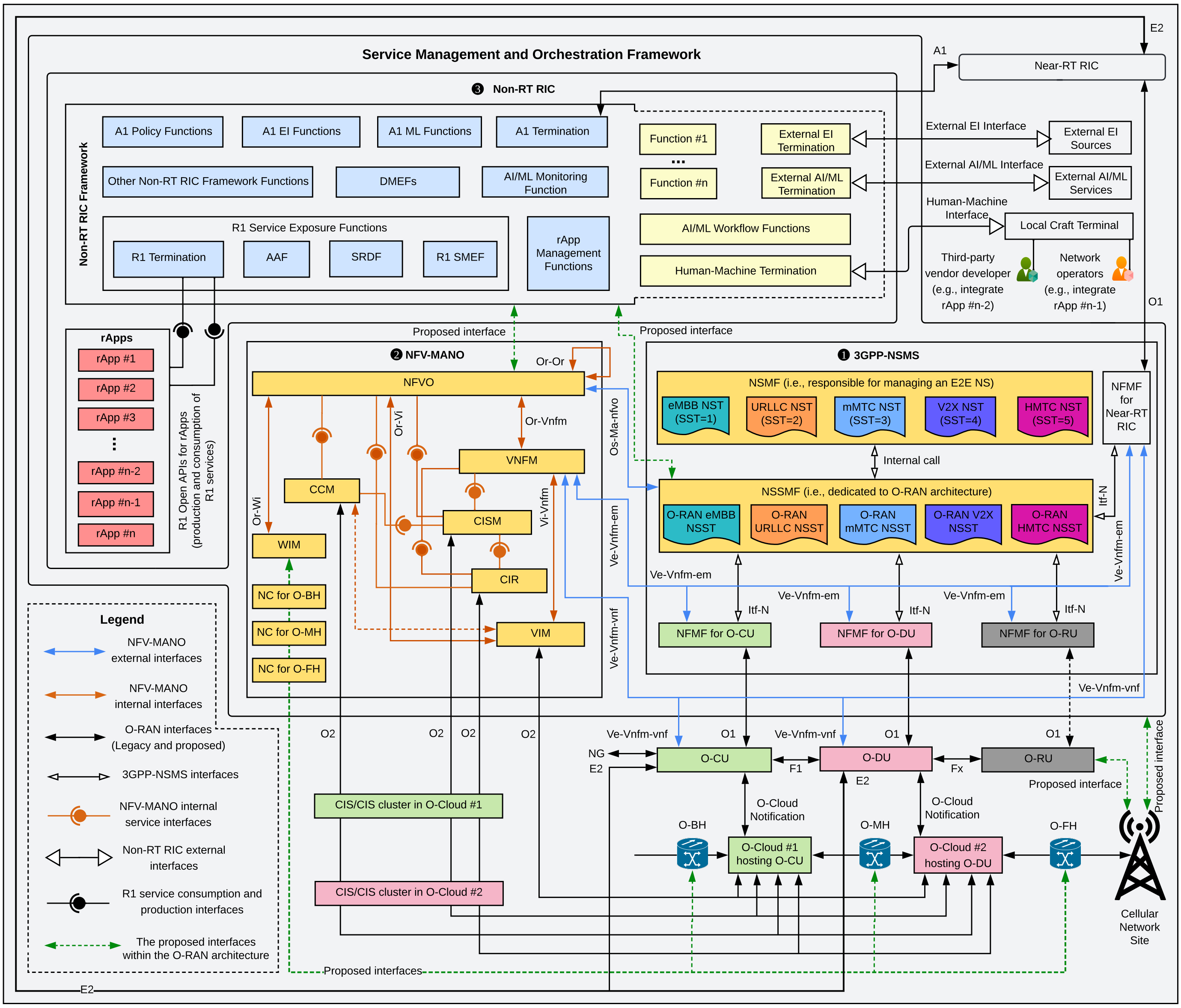

Fig. 2. The unification of 3GPP-NSMS, NFV-MANO, and Non-RT RIC within the SMO Framework in an attempt to design a unified framework for the M&O of O-RAN slices in the O-RAN slicing-aware reference architecture. Note 1: mMTC is also referred to as mIoT in 3GPP terminology. Note 2: The interaction between CCM and VIM within the NFV-MANO architecture is a subject for future study. Note 3: EI stands for enrichment information in this figure. Note 4: To ensure completeness, we have included the management components of transport links (i.e., WIM and NCs) in the figure. However, a comprehensive discussion of their roles and the M&O of transport links within the O-RAN architecture is beyond the scope of our study.

administers the O-RU via the O1 interface. The logical functionalities of an O-RU are hosted by cellular sites. To map these functionalities onto the cellular sites, a logical interface is required between the O-RU and cellular sites. In addition, a logical interface is needed between the SMO Framework and cellular sites in order to manage radio and physical resources. Figure 2 shows that the O-RAN Alliance has not yet defined these interfaces. To the best of our knowledge, we are the first to propose the two interfaces, which we believe are essential to the realization of a unified O-RAN architecture. Especially, they are critical in the M&O of shared O-RUs and mapping them onto cellular sites [5]. We denote the two interfaces as CellularSite Notification and O2, respectively. Table I provides additional information on their scope and implications.

The O-CU, O-DU, and Near-RT RIC are provided as virtual network functions (VNFs). The lifecycle management of VNFs and their connectivity with PNF(s), as well as the control of the corresponding NFMFs, from a virtualization perspective, are within the scope of the NFV-MANO. The 3GPP-NSMS exclusively manages these NFs from the viewpoint of applications. The Non-RT RIC interacts with them to optimize their operations through the use of appropriate rApps. To jointly manage the PNFs and VNFs of an O-gNB, as well as their required resources, the NSSMF initiates interaction with the NFV-MANO. Once such interoperability is established, the 3GPP-NSMS entities interwork with the NFV-MANO functional blocks (FBs) for a unified M&O of O-RAN slices [3], as shown in parts (❶) and (❷) of Figure 2.

Table I. The logical interfaces that have not yet been defined within the O-RAN architecture (see Figure 2). We prefer to denote these interfaces as analogous to the existing interfaces standardized for the O-RAN architecture to comply with the terminology and scope of the specifications of the O-RAN Alliance.

Endpoints	Proposed Interface	Scope
SMO Framework – Cellular Site	O2	This interface connects the SMO Framework to cellular sites to support the M&O capabilities of the cellular infrastructure. The scope of this interface is comparable to that of other O2 interfaces that connect the SMO Framework to O-Cloud sites hosting O-CU and O-DU. However, its scope is pertinent to radio resource management at cellular sites. This interface is anticipated to align with the 3GPP specifications for radio resource management in the O-RAN architecture to the extent possible.
O-RU – Cellular Site	CellularSite Notification	The CellularSite Notification interface enables the O-RU logical functions, which are deployed on cellular sites, to subscribe to events and/or status updates from the relevant cellular sites. The cellular sites will include event producers to allow radio resource workloads to receive events and/or status updates that are only known to the cellular infrastructure using the CellularSite Notification interface.
NC – O-BH	O2*	This interface connects the NC and O-BH. It is utilized by the WIM and NC to manage the O-BH transport links between the O-CU and core network and to orchestrate their respective networking resources, devices, and traffic. Employing the NC – O-BH interface, the WIM and NC define and configure the behavior, enforce the policies, and monitor the performance of an O-BH transport link.
NC – O-MH	O2*	This interface links the NC to the O-MH. The WIM and NC use the NC – O-MH interface to manage the O-MH transport links between the O-CU and O-DU, as well as to orchestrate networking resources, components, and traffic that exist in this transport link. The WIM and NC utilize this interface to define and configure the behavior, enforce the policies, and monitor the performance of an O-MH link.
NC – O-FH	O2*	This interface connects the NC and O-FH. The WIM and NC employ the NC – O-FH interface to manage the O-FH transport links between the O-DU and O-RU and to orchestrate their networking resources, devices, and network traffic over the O-FH transport link. The WIM relies on NC to define and configure the behavior, enforce the policies, and monitor the performance of an O-FH link.

Note*: The scope of the article precludes further analysis or discussion of the O2 interfaces proposed for transport slicing in this table.

B. NFV-MANO for O-RAN Slicing

Part (❷) of Figure 2 depicts the architecture of NFV-MANO Release 4, which includes management functions (MFs) for containerized network functions (CNFs) atop FBs proposed by the ETSI ISG NFV in previous releases. Originally, the NFV-MANO consisted of the network function virtualization orchestrator (NFVO), the virtual network function manager (VNFM), the virtualized infrastructure manager (VIM), and the wide area network infrastructure manager (WIM) [6]. The NFVO instantiates O-CU and O-DU, in addition to validating and authorizing requests for virtual resources of an O-RAN slice. It also interacts with the NSSMF to jointly manage the virtual and physical components of an O-gNB. The VNFM manages the lifecycle and FCAPS of O-CU and O-DU from a virtualization perspective. The VIM manages and orchestrates the virtual and physical resources of O-Cloud sites via the O2 interface. It also lets O-Cloud sites notify the hosted O-CU, O-DU, and Near-RT RIC of critical notifications via the O-Cloud Notification interface. The WIM manages the virtual connectivity among O-Cloud sites and between O-Cloud sites and cellular sites through the use of network controllers (NCs). Each NC manages a specific transport network. To this end, the O-RAN Alliance has not yet specified the interfaces between NCs and O-BH, O-MH, and O-FH. We are the first to propose these three interfaces for transport link management. We denote them as O2 interfaces. Further elaboration on their scope and implications is provided in Table I.

The ETSI ISG NFV has recently added several MFs to the NFV-MANO architecture to support the M&O of CNFs (e.g., if O-CU and O-DU are provided as CNFs). Specifically, they are container infrastructure service management (CISM), container image registry (CIR), and container infrastructure service cluster management (CCM) [6]. The CISM manages container-based applications and infrastructure services, including the management of containers, the orchestration of container clusters, and the management of CNFs. The CIR manages the lifecycle of container images securely and effectively, such as image storage, retrieval, modification, and deletion. The CCM provides the tools and procedures to manage the lifecycle of container infrastructure service (CIS) clusters, including deployment, scaling, and monitoring. Part (❷) of Figure 2 shows that the CNFs MFs expose a series of management services that are invoked by NFV-MANO FBs via internal interfaces and external consumers (e.g., O-Cloud sites in O-RAN architecture) via O2 interfaces. They also consume management services produced by the NFV-MANO FBs.

C. Non-RT RIC for O-RAN Slicing

Part (❸) of Figure 2 shows that rApps and the Non-RT RIC Framework are the major building blocks of the Non-RT RIC architecture. rApps utilize the capabilities and features of the Non-RT RIC (or SMO) Framework to provide value-added services [2], such as data analytics and enrichment information, associated with the operation and optimization of O-RAN slices. The Non-RT RIC Framework includes several functions that terminate the A1 interface to the Near-RT RIC, expose or consume a set of R1 services to or from the rApps, and manage various types of rApps. These functions are interconnected with one another and with rApps via Non-RT RIC internal interfaces. The Non-RT RIC Framework can also be connected to other M&O frameworks (e.g., NFV-MANO FBs, 3GPP-NSMS entities, etc.) via SMO internal interfaces. Additionally, the Non-RT RIC architecture comprises external interfaces that link the Non-RT RIC Framework and rApps to external sources and services situated outside of the SMO Framework. Furthermore, the Non-RT RIC architecture must have the ability to integrate future logical functions that may offer extra novel services via the R1 interface or additional enrichment information via the A1 interface.

1) rApps: rApps are modular software applications that use Non-RT RIC (or SMO) Framework capabilities to deliver value-added services for intelligently optimizing and operating O-RAN slices. These value-added services include, but are not limited to: (a) policy-based recommendations and enrichment information via the A1 interface; (b) data analytics, AI/ML model training, and inference for O-RAN slice optimization or other rApps; and (c) recommendations associated with configuration management actions via the O1 interface. An example of an rApp could be a module that provides real-time analytics and predictive maintenance for network components within an O-RAN slice. This module could utilize ML to analyze performance metrics from network components and generate insights to assist operators in optimizing the O-RAN slice based on data-driven decisions. A second example would be a module that provides intelligent load-balancing capabilities for traffic within an O-RAN slice by dynamically routing traffic based on network conditions and congestion levels.

rApps can be developed by third-party developers, network operators, and vendors and integrated into the Non-RT RIC via the open and standardized R1 interface. This approach fosters greater innovation, competition, and flexibility in the development of O-RAN services and applications. After a successful insertion of an rApp into the Non-RT RIC, the contained policies and recommendations are sent to the R1 termination function via the R1 interface, which then interacts with the Non-RT RIC Framework logical functions to utilize the R1 services. The R1 services provided by the Non-RT RIC include service management, data management, exposure services, A1-related services, O1-related services, O2-related services, AI/ML workflow services, etc. The R1 services can be generated by logical functions within the Non-RT RIC (or SMO) Framework or by rApps. Additionally, R1 service providers can also be R1 service consumers.

2) Non-RT RIC Framework: Part (❸) of Figure 2 shows that the Non-RT RIC architecture consists of functions anchored inside (in Pattens Blue) and outside (in Lemon Chiffon) the Non-RT RIC Framework. In certain deployment scenarios, some functions of the two categories may also be regarded as non-anchored functions that may or may not be included in the Non-RT RIC Framework. Moreover, there may be functions anchored outside of the SMO Framework that can assist the Non-RT RIC Framework in tasks such as the ingestion of enrichment information, the training of AI/ML models, and the manual insertion of rApps into the Non-RT RIC by technicians. Each function (of the aforementioned two categories) can interact not only with functions within its own category but also with functions of another category, as well as functions located outside of the SMO Framework, via implementation-specific internal and external interfaces. In this article, we focus on the structure of the SMO Framework, omitting the deployment and functional aspects. Hence, we choose to (a) consider the categorization of functions inside and outside the Non-RT RIC Framework as a deployment matter, and (b) omit discussion on the interconnection between functions, leaving it to the discretion of vendors and operators to design the

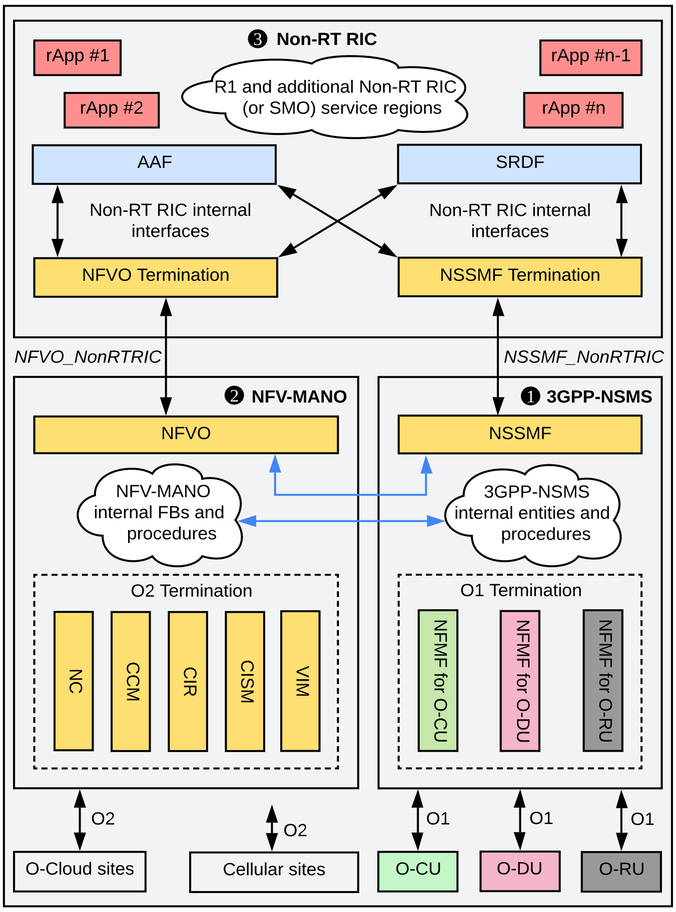

Fig. 3. The proposed architectural solution for realizing standard-compliant interoperability among the Non-RT RIC, NFVO, and NSSMF.

interconnection and deployment of said functions within the Non-RT RIC architecture. Nevertheless, we cover the necessary features and capabilities of anchored and non-anchored functions as per the latest O-RAN Alliance specifications.

The functions anchored inside the Non-RT RIC Framework include R1 Service Exposure Functions, rApps Management Functions, A1-related Functions, AI/ML Monitoring Function, Data Management and Exposure Functions (DMEFs), and Other Non-RT RIC Framework Functions, as portrayed in part (❸) of Figure 2. The R1 Service Exposure Functions enable a range of services such as service discovery, registration, notification, authorization, and authentication through Authentication and Authorization Function (AAF), Service Registration and Discovery Function (SRDF), and R1 Service Management and Exposure Function (SMEF). The AAF provides authorization and authentication for rApps prior to granting them access to the R1 services. The SRDF enables rApps to discover and register for the desired R1 services. The R1 SMEF offers management and exposure services to R1 service consumers and providers and enables interaction between the two parties. The R1 services are facilitated by the R1 Termination Function, which allows the exchange of messages between the rApps and the Non-RT RIC Framework, thereby empowering the rApps to access the R1 services via the R1 interface. The rApp Management Functions are responsible for resolving

Table II. The definitions, scope, and implications of the two proposed functions that facilitate interoperability among the Non-RT RIC, NSSMF, and NFVO.

Proposed Termination	Scope
NSSMF Termination	The NSSMF Termination enables the NSSMF (and other 3GPP-NSMS entities used for the M&O of an O-RAN slice) to send and receive messages to and from the Non-RT RIC via the `NSSMF_NonRTRIC` interface, with the goal of subscribing to and utilizing certain services and capabilities of the Non-RT RIC and rApps. In addition, this logical function permits the Non-RT RIC and an rApp to send and receive messages to and from NSSMF in an effort to influence decisions made by the 3GPP-NSMS. The messages exchanged between the NSSMF and the Non-RT RIC primarily consist of the following types: (a) handshaking messages, establishing an authorized connection between the Non-RT RIC and NSSMF; (b) request/response messages, requesting information or services from NSSMF/Non-RT RIC and receiving a response in return; (c) acknowledgment messages, confirming that a particular message or service has been received successfully; (d) control messages, managing and controlling the exchange of messages between the Non-RT RIC and NSSMF; and (e) error messages, indicating and reporting errors or exceptional conditions that occur during the interaction between the Non-RT RIC and NSSMF. Overall, the messages encompass various protocols necessary for seamless communication and interoperability between the Non-RT RIC and NSSMF.
NFVO Termination	The NFVO Termination facilitates the exchange of messages between the NFVO (and other FBs and CNFs MFs used for the M&O of the virtualized parts of an O-RAN slice) and Non-RT RIC via the `NFVO_NonRTRIC` interface. It allows the NFVO to exchange messages with the Non-RT RIC to gain authorized access to its capabilities and features, as well as to the rApps. This logical function also enables the Non-RT RIC and an rApp to send and receive messages to and from the NFVO aimed at influencing the internal procedures and decisions made by the NFV-MANO with respect to the virtualized and cloudified aspects of various types of O-RAN slices. The most common messages exchanged between the NFVO and the Non-RT RIC include: (a) handshaking messages, initiating an authorized interaction between the Non-RT RIC and NFVO; (b) request/response messages, inquiring information or services from the NFVO/Non-RT RIC and receiving a corresponding response; (c) acknowledgment messages, affirming the successful receipt of a specific message; (d) control messages, managing and controlling the exchange of messages between the Non-RT RIC and NFVO; and (e) error messages, indicating and reporting errors or exceptional conditions that occur during the interaction between the Non-RT RIC and NFVO. These messages facilitate effective communication and coordination between the NFVO and Non-RT RIC, ensuring the smooth operation and maintenance of their interoperability.

any potential conflicts that may emerge between rApps. A1-related Functions (namely Policy, Enrichment Information, and ML) produce A1 policy services, handle A1 enrichment information services, and enable/route A1-related ML services, respectively. The produced A1-related services are exposed to the rApps via the R1 interface and to the Near-RT RIC via the A1 interface, interfacing the R1 Termination Function and the A1 Termination Function, respectively. The AI/ML Monitoring Function ensures that various AI/ML models are functioning normally in multi-vendor scenarios through online monitoring services. The DMEFs provide the data registration, discovery, request, subscription, delivery, offer, and processing services between the data producers and consumers within the Non-RT RIC (or SMO) Framework and beyond. Lastly, Other Non-RT RIC Framework Functions accommodate any potential future functions identified in later studies.

Part (❸) of Figure 2 also depicts that a number of functions anchored outside of the Non-RT RIC Framework interact with external services and sources placed outside of the SMO Framework via their respective external interfaces. The External Enrichment Information Termination Function assists the Non-RT RIC Framework in collecting external enrichment information from external sources for improving the performance of rApps and R1 services. There is also an External AI/ML Termination Function that can be used to import trained ML models (along with their metadata) from an external AI/ML server into the Non-RT RIC Framework, thus further enhancing the capabilities of the Non-RT RIC architecture. The Human-Machine Termination Function enables technicians to access the Non-RT RIC for injecting O-RAN intents and operating rApps via an application programming interface (API). Moreover, the AI/ML Workflow Functions produce AI/ML workflow services. Finally, Function $\#1$ – Function $\#\mathrm{n}$ serve as placeholders for potential future functions that could be incorporated into the Non-RT RIC architecture.

III. Proposal for Enabling Interoperability Among Non-RT RIC, 3GPP-NSMS, and NFV-MANO

This section proposes an architectural solution that facilitates standard-compliant interoperability among 3GPP-NSMS, NFV-MANO, and Non-RT RIC. It also examines the potential influence of Non-RT RIC on the O1 and O2 interfaces, as well as explores the enhanced capabilities that could result from such interoperability for 3GPP-NSMS and NFV-MANO.

A. The Interworking of NSSMF, NFVO, and Non-RT RIC

To enable interoperability among the three modules within the SMO Framework, we introduce two logical functions (a.k.a. terminations) to the Non-RT RIC architecture, namely the NFVO Termination and the NSSMF Termination, as shown in part (❸) of Figure 3. The former links the NFVO and Non-RT RIC, while the latter connects the NSSMF with the Non-RT RIC. We provide additional information regarding their definitions, scope, and implications in Table II. Both functions can be situated inside or outside the Non-RT RIC Framework. However, they are considered as parts of the Non-RT RIC architecture. The goal of this interoperability is to grant Non-RT RIC access to the NFVO and NSSMF, allowing it to influence the decisions made by their managing components and interfaces. Additionally, this interoperability authorizes the NFVO and NSSMF to access the R1 services and rApps, thereby enhancing the capabilities of their internal procedures and the O1 and O2 interfaces. The proposed interconnection between the three modules shall be made via standard-compliant interfaces. To date, the O-RAN Alliance has not yet defined such interoperability or the interfaces that connect these modules. To address this issue, we propose two interfaces between the three modules, as illustrated in Figure 3. We denote the interface between the NFVO and Non-RT RIC as `NFVO_NonRTRIC` and the interface between the NSSMF and Non-RT RIC as `NSSMF_NonRTRIC`. More details on their scope and implications are provided in Table III.

Table III. The detailed description of the two logical interfaces that connect the two proposed terminations between the Non-RT RIC, NSSMF, and NFVO.

Endpoints	Proposed Interface	Scope
NSSMF – Non-RT RIC	NSSMF_NonRTRIC	The NSSMF_NonRTRIC interface connects the NSSMF and NSSMF Termination to enable seamless interoperability and data exchange between the 3GPP-NSMS and the Non-RT RIC. This interface shall perform the most critical functionalities that are required to be executed while connecting the NSSMF and the Non-RT RIC. These functionalities mainly involve protocol conversion, data encapsulation and decapsulation, addressing and routing, data link control, flow control, security and encryption, error handling, synchronization, performance monitoring, and others. The NSSMF_NonRTRIC interface performs these functionalities on the messages and data (see Table II) that are exchanged between the two entities, ensuring compatibility, reliability, and security across the entire SMO Framework.
NFVO – Non-RT RIC	NFVO_NonRTRIC	The NFVO_NonRTRIC interface enables smooth interoperability and message exchange between the NFV-MANO and Non-RT RIC by connecting the NFVO and NFVO Termination. This interface plays a crucial role in enabling seamless communication by performing various critical functionalities. The functionalities of the NFVO_NonRTRIC interface comprise tasks comparable to those listed for the NSSMF_NonRTRIC interface above. By efficiently executing most of these tasks on the exchanged messages and data of various types of O-RAN slices, the NFVO_NonRTRIC interface is expected to ensure compatibility, reliability, security, and privacy between the NFV-MANO and Non-RT RIC.

To deploy the proposed interfaces between the three modules, there are two possible deployment options. The first option involves the Non-RT RIC interacting solely with NSSMF. The NSSMF then interacts with NFVO. In our previous work [3], we proposed a framework that facilitates interoperability among the 3GPP-NSMS and NFV-MANO. In the first option, we assume that the joint interactions and workflows between the NSSMF and NFVO are executed in the same manner. Hence, the NFVO_NonRTRIC interface can be disabled in the first option. The second deployment option entails the Non-RT RIC interacting directly with NSSMF and NFVO. Thus, the two interfaces are enabled in the second option. Each deployment option has advantages and challenges. For a more in-depth examination of interoperability among the three modules using the proposed functions and interfaces, Figure 3 portrays our adoption of the second option.

The NFVO Termination and NSSMF Termination are connected to the AAF and the SRDF via Non-RT RIC internal interfaces. The AAF is responsible for verifying the identities of the NFVO and NSSMF when they access the Non-RT RIC. Additionally, the AAF also verifies the R1 services, which are produced by the Non-RT RIC and rApps, that the NFVO and NSSMF will consume. After completing the authentication of R1 services, as well as service consumers and producers, this function is granting or denying service consumption and production requests based on either vendor-specific algorithms or network operator policies. The access requests and other messages between the three modules are exchanged via the NFVO_NonRTRIC and NSSMF_NonRTRIC interfaces. The SRDF permits the NFVO and NSSMF to discover, register, and de-register R1 services and rApps within SMO service regions. This function can also include profiles for R1 services and rApps to improve service discovery and registration. When required, both proposed terminations shall have the capabilities to connect with other legacy and future logical functions anchored within and outside the Non-RT RIC Framework.

From the perspective of the SMO Framework, the NFMFs and VIM (along with CISM, CIR, CCM, and NC) are viewed as the O1 Termination and O2 Termination, respectively. These two terminations are anchored outside the Non-RT RIC architecture, as shown in parts (❶) and (❷) of Figure 3. The O1 Termination is connected to the NSSMF via the 3GPP-NSMS internal interfaces and then linked to the Non-RT RIC via the NSSMF_NonRTRIC interface. The O2 Termination (except O2 Termination for cellular sites) is connected to NFVO via the NFV-MANO internal interfaces. The NFVO is then linked to the Non-RT RIC via the NFVO_NonRTRIC interface.

B. Influence of Non-RT RIC on the O1 and O2 Interfaces

Once interoperability among the three modules is established, the Non-RT RIC is able to access the NFVO and NSSMF in order to influence their internal procedures and the decisions made via the O1 and O2 interfaces. This specifically means that the Non-RT RIC assists the 3GPP-NSMS entities in optimizing the performance of the O-RAN slice-specific functionalities and operations, such as lifecycle management and FCAPS, according to the O-RAN NSSTs. The Non-RT RIC does so by providing policy-based recommendations and implementing them via the O1 Termination. Furthermore, the Non-RT RIC provides enrichment information and recommendations to the NFV-MANO, directly or indirectly, to enhance its functionalities and operations regarding the M&O of VNFs, CNFs, and the underlying virtualized and cloudified resources via the O2 Termination. The Non-RT RIC can provide these value-added services by developing tailored rApps (which may relate to the M&O services or O-RAN slice performance optimization) that allow the Non-RT RIC to implement control actions and policies via the O1 and O2 Terminations. It should be noted that the scope of the Non-RT RIC in the proposed solution is limited to improving the performance of the functionalities and operations of the NFV-MANO and 3GPP-NSMS through the addition of new capabilities and features. It does not necessarily interfere with or modify the M&O functionalities of the two modules.

To offer value-added services, the Non-RT RIC collects a significant amount of data containing multiple parameters related to the O-RAN slices from the 3GPP-NSMS and NFV-MANO, utilizing interfaces such as NFVO_NonRTRIC and NSSMF_NonRTRIC, as well as logical functions such as O1 Termination and O2 Termination. The collected data is related to the M&O services and FCAPS functionalities that are gathered from various sources such as E2 nodes, O-Cloud sites, and cellular network sites. The Non-RT RIC uses the collected data to train its ML model, utilizing either External AI/ML Services or an internal logical function (see Figure 2). The trained model is then employed by the Non-RT RIC to improve rApps' performance objectives and enhance the Non-RT RIC services. Finally, the rApps and Non-RT RIC provide the policies and recommendations generated by the trained ML model to 3GPP-NSMS and NFV-MANO.

C. 3GPP-NSMS and NFV-MANO Capabilities Enhancement

The 3GPP-NSMS can access the R1 services and rApps via the `NSSMF_NonRTRIC` interface to enhance the capabilities of its entities and interfaces, as well as to optimize its interaction with NFV-MANO and other managed and managing systems within and beyond the SMO Framework. Once authorized access to Non-RT RIC capabilities has been granted, the NSSMF employs R1 services and rApps features and can also expose them to the remaining entities and interfaces of the 3GPP-NSMS. For example, an rApp designed to assist NSSMF in selecting appropriate NFMFs for intelligently and optimally managing the FCAPS of the O-gNB NFs is installed in the Non-RT RIC. The NSSMF leverages the capabilities of this particular rApp to enhance its functionalities and those of NFMFs with respect to the FCAPS of respective O-gNBs in its service region. By leveraging the Non-RT RIC capabilities via the `NSSMF_NonRTRIC` interface and NSSMF Termination, the network operator can optimize the performance of the entities and interfaces of the 3GPP-NSMS.

The NFV-MANO can also enhance its capability by accessing and leveraging authorized rApps and R1 services via the `NFVO_NonRTRIC` interface. Once the NFVO has been granted access to the Non-RT RIC, it utilizes the capabilities of the Non-RT RIC and can also expose them to the remaining NFV-MANO FBs and CNFs MFs. Additionally, the NFV-MANO can optimize its interactions with the underlying infrastructure, 3GPP-NSMS, and other M&O systems by leveraging the Non-RT RIC capabilities. For instance, an rApp is designed and installed in the Non-RT RIC to assist the NFV-MANO in intelligently mapping the VNFs and CNFs of an O-RAN slice onto the underlying cloudified and virtualized O-Cloud sites. The NFVO leverages this rApp and exposes its capabilities to the VIM and O-Cloud sites via standardized interfaces during the placement of the NFs of an O-RAN slice onto the underlying infrastructure. We foresee that leveraging the Non-RT RIC capabilities by the NFV-MANO via the `NFVO_NonRTRIC` and NFVO Termination will enhance the performance of its FBs and CNFs MFs.

IV. Concluding Remarks and Future Outlook

In this article, we designed a unified SMO Framework for the M&O of O-RAN slices by unifying the standards of 3GPP TSG SA5, ETSI ISG NFV, and the O-RAN Alliance. To facilitate standard-compliant interoperability among the three modules, we have proposed two logical functions and their corresponding interfaces to be integrated into the SMO Framework. We are confident that the proposed architectural model will serve as a comprehensive M&O solution for managing the components of O-RAN slices and orchestrating their required resources across the O-Cloud sites. In terms of future studies, there are two significant research challenges that must be addressed. Our first goal is to extend the current work by exploring the implementation of standard-compliant AI/ML features and capabilities within the SMO Framework. By doing so, we aim to enhance the M&O of O-RAN slices and improve the overall performance of O-RAN architecture. Achieving this goal will require further research, but we believe that it will ultimately result in more efficient and effective M&O solutions. Secondly, we are interested in exploring the M&O of transport slicing in the O-RAN architecture in greater depth. We recognize that transport NSSs play a critical role in ensuring the overall performance and reliability of O-RAN slices, and we believe that investigating their M&O will be an important area of future research.

Appendix A

Drawing upon the preceding sections, the O-RAN Alliance considers three functions within the Non-RT RIC architecture, enabling its intelligence and automation. They are the AI/ML Monitoring Function, the External AI/ML Termination Function, and the AI/ML Workflow Functions. We propose their integration into a unified function. The proposed function is referred to as the AI/ML Function, encompassing the above and any additional functions. Further discussion on the AI/ML Function can be considered in future studies of this work.

Appendix B

To further illustrate the implementation of our proposed logical interfaces and functions, which are detailed in Tables II and III, we have provided Swagger API specifications in [Click Here]. These specifications describe the usage of a Unified O-RAN Slice Lifecycle Management API within the proposed SMO Framework. The API outlines endpoints for managing `NSSMF_NonRTRIC` entries and `NFVO_NonRTRIC` entries, facilitating operations such as creation, retrieval, update, and deletion. Additionally, the API supports message exchange between NSSMF and Non-RT RIC and NFVO and Non-RT RIC. Descriptions of request parameters and response structures are included, covering O-RAN slice information, service types, quality of service profiles, security levels, etc.

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References

[1] O-RAN Alliance, "Working Group 1; Study on O-RAN Slicing; Technical Report; V02.00." Alfter, Germany, Apr. 2020.
[2] O-RAN Alliance, "Working Group 2; Non-RT RIC Architecture; Technical Specification; V02.01." Alfter, Germany, Oct. 2022.
[3] M. A. Habibi, F. Z. Yousaf, and H. D. Schotten, "Mapping the VNFs and VLs of a RAN Slice Onto Intelligent PoPs in Beyond 5G Mobile Networks," *IEEE Open J. Commun. Soc.*, vol. 3, pp. 670–704, 2022.
[4] 3GPP TSG SA5, "3GPP TR 28.801; Technical Specification Group Services and System Aspects; Telecommunication management; Study on Management and Orchestration of Network Slicing for Next Generation Network (Release 15); V15.1.0 ." Jan. 2018.
[5] O-RAN Alliance, "Working Group 4 (Open Fronthaul Interfaces); Control, User and Synchronization Plane Specification; Technical Specification; V12.00." Alfter, Germany, Jun. 2023.
[6] ETSI ISG NFV, "ETSI GS NFV 006; Network Functions Virtualisation (NFV) Release 4; Management and Orchestration; Architectural Framework Specification; V4.4.1." Sophia Antipolis, France, Dec. 2022.