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Technical Specification

O-RAN Working Group 3
Near-Real-time RAN Intelligent Controller
Near-RT RIC Architecture

Revision History

Date	Revision	Author	Description
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Contents

Foreword

This Technical Specification has been produced by the O-RAN Alliance.

The contents of the present document are subject to continuing work within O-RAN and may change following formal O-RAN approval. Should the O-RAN Alliance modify the contents of the present document, it will be re-released by O-RAN with an identifying change of release date and an increase in version number as follows:

Release x.y.z

where:

- x the first digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc. (the initial approved document will have x=01).
- y the second digit is incremented when editorial only changes have been incorporated in the document.
- z the third digit included only in working versions of the document indicating incremental changes during the editing process.

1 Scope

The present document specifies the overall architecture of the Near-RT-RIC (RAN Intelligent Controller) and function descriptions, including the interaction between hosted applications and common functions in the Near-RT RIC.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] O-RAN-WG3.E2GAP, “O-RAN Working Group 3, Near-Real-time RAN Intelligent Controller, E2 General Aspects and Principles”.

[3] O-RAN-WG3.E2AP, “O-RAN Working Group 3, Near-Real-time RAN Intelligent Controller, E2 Application Protocol (E2AP)”.

[4] O-RAN-WG1.OAM Architecture, “O-RAN Operations and Maintenance Architecture”.

[5] O-RAN-WG1.O1-Interface, “O-RAN Operations and Maintenance Interface Specification”.

[6] 3GPP TS 33.401: “3GPP System Architecture Evolution (SAE); Security architecture”.

[7] 3GPP TS 33.501: “Security architecture and procedures for 5G System”.

[8] O-RAN-WG2.A1.GA&P, “O-RAN Working Group 2, A1 interface: General Aspects and Principles”.

[9] O-RAN-WG2.A1AP, “O-RAN Working Group 2, A1 Interface: Application Protocol”.

[10] O-RAN-WG1.O-RAN Architecture, “O-RAN Working Group 1, O-RAN Architecture Description”.

[11] 3GPP TS 36.401: "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Architecture Description".

[12] 3GPP TS 38.300: “NR; NR and NG-RAN Overall Description; Stage 2”.

3 Definitions and Abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in TR 21.905 [1].

Near-RT RIC (O-RAN near-real-time RAN Intelligent Controller): a logical function that enables near-real-time control and optimization of RAN elements and resources via fine-grained (e.g. UE basis, Cell basis) data collection and actions over E2 interface.

non-RT RIC(O-RAN non-real-time RAN Intelligent Controller): a logical function that enables non-real-time control and optimization of RAN elements and resources, AI/ML workflow including model training and updates, and policy-based guidance of applications/features in Near-RT RIC.

O-CU: O-RAN Central Unit: a logical node hosting RRC, SDAP and PDCP protocols.

O-CU-CP: O-RAN Central Unit – Control Plane: a logical node hosting the RRC and the control plane part of the PDCP protocol.

O-CU-UP: O-RAN Central Unit – User Plane: a logical node hosting the user plane part of the PDCP protocol and the SDAP protocol.

O-DU: O-RAN Distributed Unit: a logical node hosting RLC/MAC/High-PHY layers based on a lower layer functional split.

O-RU: O-RAN Radio Unit: a logical node hosting Low-PHY layer and RF processing based on a lower layer functional split. This is similar to 3GPP’s “TRP” or “RRH” but more specific in including the Low-PHY layer (FFT/iFFT, PRACH extraction).

O-eNB (O-RAN eNB): an eNB [10] or ng-eNB [11] that supports E2 interface.

O1: Interface between orchestration & management entities (Orchestration/NMS) and O-RAN managed elements, for operation and management, by which FCAPS management, Software management, File management and other similar functions shall be achieved.

SMO: Service Management and Orchestration system.

A1: Interface between non-RT RIC and Near-RT RIC to enable policy-driven guidance of Near-RT RIC applications/functions, and support AI/ML workflow.

E2: Interface connecting the Near-RT RIC and one or more O-CU-CPs, one or more O-CU-UPs, and one or more O-DUs.

E2 Node: a logical node terminating E2 interface. In this version of the specification, ORAN nodes terminating E2 interface are:

- for NR access: O-CU-CP, O-CU-UP, O-DU or any combination as defined in [4];
- for E-UTRA access: O-eNB.

xApp: An application designed to run on the Near-RT RIC. Such an application is likely to consist of one or more microservices and at the point of on-boarding will identify which data it consumes and which data it provides. The application is independent of the Near-RT RIC and may be provided by any third party. The E2 enables a direct association between the xApp and the RAN functionality.

O-Cloud: O-Cloud is a cloud computing platform comprising a collection of physical infrastructure nodes that meet O-RAN requirements to host the relevant O-RAN functions (such as Near-RT RIC, O-CU-CP, O-CU-UP, and O-DU), the supporting software components (such as Operating System, Virtual Machine Monitor, Container Runtime, etc.) and the appropriate management and orchestration functions.

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply.

API	Application Programming Interface
FM	Fault Management
LCM	Life-Cycle Management
ML	Machine Learning
non-RT RIC	non-real-time RAN Intelligent Controller:
Near-RT RIC	near-real-time RAN Intelligent Controller
O-CU	O-RAN Central Unit
O-CU-CP	O-RAN Central Unit – Control Plane
O-CU-UP	O-RAN Central Unit – User Plane
O-DU	O-RAN Distributed Unit
O-RU	O-RAN Radio Unit
PM	Performance Management
SMO	Service Management and Orchestration

4 General Principles

The Near-RT RIC architecture shall follow the general architecture principles specified in [2], and the following principle(s):

- The Near-RT RIC architecture and internal interfaces shall be open to support 3rd party xApps.

5 Near-RT RIC Architecture

5.1 Requirements

The Near-RT RIC architecture shall follow the Near-RT RIC requirements specified in [2], and the following requirements:

- The Near-RT RIC shall consist of multiple xApps and a set of framework functions that are commonly used to support the specific functions hosted by xApps.
- The Near-RT RIC shall provide an open framework to allow on-boarding and Life Cycle Management (LCM) of xApps to support Near-RT RIC related use cases.

5.1.1 Framework Requirements

- The Near-RT RIC shall provide a database function that stores the configurations relating to E2 nodes, Cells, Bearers, Flows, UEs and the mappings between them.
- The Near-RT RIC shall provide ML tools that support data pipelining.
- The Near-RT RIC shall provide a messaging infrastructure.

- The Near-RT RIC shall provide logging, tracing and metrics collection from Near-RT RIC framework and xApps to SMO.
- The Near-RT RIC shall provide security functions.
- The Near-RT RIC shall support conflict resolution to resolve the potential conflicts or overlaps which may be caused by the requests from xApps.

5.1.2 xApp Requirements

- xApps may enhance the RRM capabilities of Near-RT RIC.
- xApps shall provide logging, tracing and metrics collection to the Near-RT RIC.
- xApps shall provide a descriptor that will include basic information (configuration, metrics and control) about the xApp.
- xApp descriptor components shall include the following:

  - Configuration: The xApp configuration specification shall include a data dictionary for the configuration data, i.e., meta data such as a yang definition or a list of configuration parameters and their semantics. Additionally it may include an initial configuration of xApps.

  - Control: xApp controls specification shall include the types of data it consumes and provides that enable control capabilities (e.g. xApp URL, parameters, input/output type).

  - Metrics: The xApp metrics specification shall include a list of metrics (e.g., metric name, type, unit and semantics) provided by the xApp.

- The xApp descriptor shall also provide the necessary data to enable their management and orchestration. The specific requirements for these descriptors shall be aligned with [4].

5.1.3 Open API Requirements

- Near-RT RIC shall provide an open API enabling the hosting of 3rd party xApps and xApps from the Near-RT RIC platform vendor.
- Near-RT RIC shall provide an open API decoupled from specific implementation solutions, including a Shared Data Layer (SDL) that works as an overlay for underlying databases and enables simplified data access.

Note: Communication between xApps is for further study.

5.2 Overall Architecture Description

The overall architecture of O-RAN described in [10] specifies the location and interfaces of Near-RT RIC, as well as possible deployment options.

The RRM functional allocation between the Near-RT RIC and the E2 node is described in [2].

6 Near-RT RIC Functions Description

6.1 General

The Near-RT RIC hosts the following functions:

- Database, which allows reading and writing of RAN/UE information;
- xApp subscription management, which merges subscriptions from different xApps and provides unified data distribution to xApps;

- Conflict mitigation, which resolves potentially overlapping or conflicting requests from multiple xApps;
- Messaging infrastructure, which enables message interaction amongst Near-RT RIC internal functions;
- Security, which provides the security scheme for the xApps;
- Management services;
  - Fault management, configuration management, and performance management as a service producer to SMO;
  - Life-cycle management of xApps;
  - Logging, tracing and metrics collection, which capture, monitor and collect the status of Near-RT RIC internals and can be transferred to external system for further evaluation;
- Interface Termination
  - E2 termination, which terminates the E2 interface from an E2 Node;
  - A1 termination, which terminates the A1 interface from the non-RT RIC;
  - O1 termination, which terminates the O1 interface from SMO;
- Functions hosted by xApps, which allow services to be executed at the Near-RT RIC and the outcomes sent to the E2 Nodes via E2 interface.

This is summarized in the figure below.

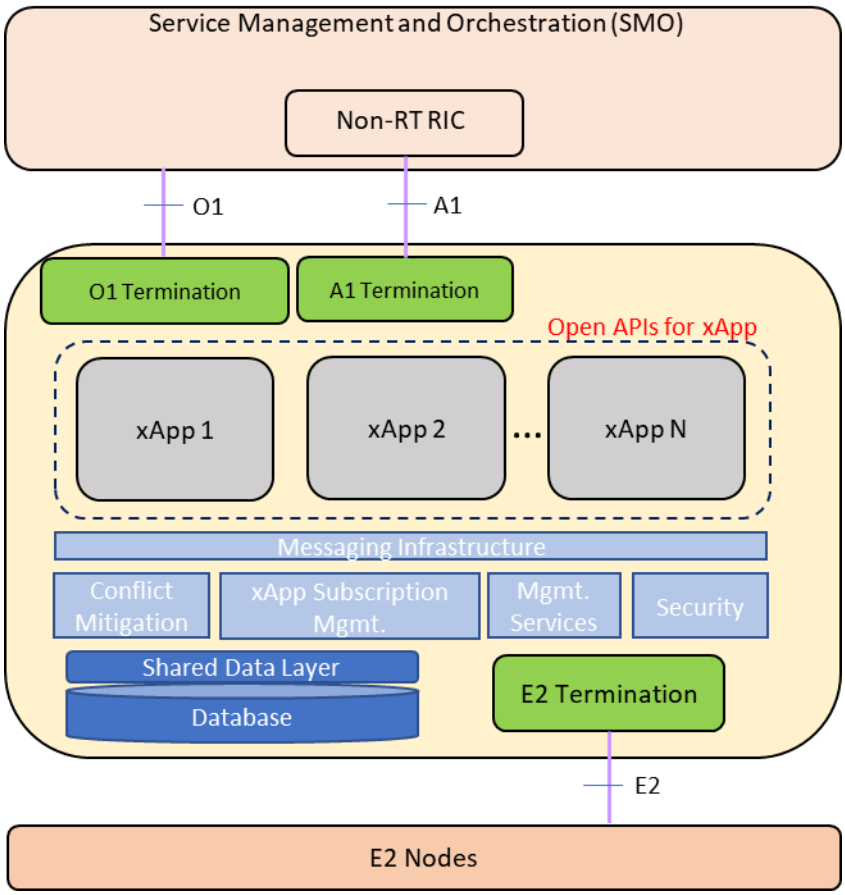

Figure 6.1-1 Near-RT RIC Internal Architecture

6.2 Framework Functions

6.2.1 Database

6.2.1.1 UE-NIB

xApps may provide UE related information to be stored in the UE-NIB (UE-Network Information Base) database.

- UE-NIB maintains a list of UEs and associated data.
- UE-NIB maintains tracking and correlation of the UE identities associated with the connected E2 nodes.

6.2.1.2 R-NIB

xApps may provide radio access network related information to be stored in the R-NIB (Radio-Network Information Base) database

- The R-NIB stores the configurations and near real-time information relating to connected E2 Nodes and the mappings between them.

6.2.2 xApp Subscription Management

- xApp subscription management manages subscriptions from the xApps to the E2 Nodes.
- xApp subscription management enforces authorization of policies controlling xApp access to messages.
- xApp subscription management enables merging of identical subscriptions from different xApps into a single subscription to the E2 Node.

6.2.3 Conflict Mitigation

In the context of the Near-RT RIC, Conflict Mitigation is about addressing conflicting interactions between different xApps. An application will typically change one or more parameters with the objective of optimizing a specific metric. Conflict Mitigation is necessary because xApps objectives may be chosen/configured such that they result in conflicting actions.

The control target of the radio resource management can be cell, UE or bearer, etc. The control contents of the radio resource management can cover the access control, the bearer control, the handover control, the QoS control, the resource assignment and so on. The control time span indicates the valid control duration which is expected by the control request. The conflicts of control can be illustrated as below.

1) Direct Conflicts: The conflicts can be observed directly by Conflict Mitigation. Some cases are described as below:

   - Two or more xApps request different settings for the very same configuration of one or more parameters of a Control Target. Conflict mitigation processes the requests and decides on a resolution.

   - The new request from an xApp may conflict with the running configuration resulting from a previous request of another or the same xApp.

   - The total requested resources from different xApps may exceed the limitation of the RAN system, e.g. the sum of resources required by the two different xApps may be far beyond the resource limitation of the RAN system.

2) Indirect Conflicts: The conflicts cannot be observed directly, nevertheless, some dependence among the parameters and resources that the xApps target can be observed. Conflict Mitigation may anticipate the possible conflicts and take actions to mitigate them. For instance, different xApps target different configuration parameters to optimize the same metric according to the respective objective. Even though this will not result in conflicting parameter settings, it may have uncontrollable or inadvertent system impacts. One example of such indirect conflicts can occur when the changes required by one xApp create a system impact which is equivalent to a parameter change targeted by another xApp. E.g., antenna tilts and Measurement offsets are different control points, but they both impact the handover boundary.

3) Implicit Conflicts: The conflicts cannot be observed directly, even the dependence between xApps are not obvious. For instance, different xApps may optimizing different metrics by (re-)configuring different parameters.

Nonetheless, optimizing one metric may have implicit, unwanted, and maybe adversary side effects on one of the metrics optimized by another xApp. E.g., protecting throughput metrics for GBR users may degrade non GBR metrics or even Cell Throughput.

For mitigating these conflicts, different approaches exist:

1) Direct conflicts typically can be mitigated by pre-action coordination, i.e., the xApps or a Conflict Mitigation component needs to make the final determination on whether any specific change is made or in which order the changes are applied.

2) Indirect conflicts can be resolved by post-action verification. Here, the actions are executed and the effects on the target metric are observed. Based on the observations, the system has to decide on potential corrections, e.g., rolling back one of the xApp actions.

3) Implicit conflicts are the most difficult to mitigate since these dependencies are difficult or impossible to observe and therefore hard to model in any mitigation scheme. In some cases, it may be possible to design around such conflicts by ensuring that Use Cases (xApps) target different parameters, thus falling back to approach 2), but preferably, a generic approach to managing such conflicts is established.

The individual xApp goals are defined by A1 policies, but it is also important to define utility metrics that incorporate the relative importance of each of the metrics targeted by the xApps as well as the importance of the optimization (use case). A Conflict Mitigation function may also use ML approaches, e.g., Reinforcement Learning, to a-priori assess, for each proposed change, the likely probability of degrading a metric versus the potential improvement.

6.2.4 Messaging Infrastructure

Messaging infrastructure provides low-latency message delivery service between Near-RT RIC internal endpoints.

- It supports registration/discovery/deletion of endpoints.
  - Registration: Endpoints register themselves to the messaging infrastructure;
  - Discovery: Endpoints are discovered by the messaging infrastructure initially and registered to the messaging infrastructure;
  - Deletion: Endpoints are deleted once they are not used anymore.
- It provides the following kinds of APIs:
  - An API for sending messages to the messaging infrastructure;
  - An API for receiving messages from the messaging infrastructure.
- It supports multiple messaging modes, e.g. point-to-point mode (e.g. message exchange among endpoints), publish/subscribe mode (e.g. real-time data dispatching from E2 termination to multiple subscriber xApps).
- It provides message routing, namely according to the message routing information, messages can be dispatched to different endpoints.
- It supports message robustness to avoid data loss during a messaging infrastructure outage/restart or to release resources from the messaging infrastructure once a message is outdated.

6.2.5 Security

The security function given in this section only applies to the Near-RT RIC. One target of security function is to prevent malicious xApps from abusing radio network information (e.g. exporting to unauthorized external systems) and/or control capabilities over RAN functions. The security requirements for the 3GPP LTE eNB is defined in [6] and for the 5G NR gNB in [7].

Note: The description of security functions is not be included in the first release.

6.2.6 Management Services

6.2.6.1 Life-Cycle Management of xApp

The life-cycle management of xApps provides the following functions.

- Onboarding xApps: It receives and stores xApp descriptor that contains configuration data for the xApp.
- Deployment of xApps: It retrieves xApp name and other information (e.g. helm chart of the xApp) from stored xApp descriptor and deploys the xApp.
- Resource management (RM): It does comprehensive resource provisioning/control for xApps on Near-RT RIC as well as monitors their latency and resource consumption characteristics to see if individual xApps meet their latency requirements. It may trigger the alarm event when they miss the critical latency requirements.
- Termination of xApps: It terminates a running xApp if the xApp is no longer needed. The resource used by the xApp will be released.

Note: LCM of the Near-RT RIC as a NF (Network Function) will be done by SMO via O-Cloud. However, it is not clear yet whether LCM of xApps will be done by SMO or Near-RT RIC. This section is present under the assumption that LCM of xApps is performed by Near-RT RIC.

6.2.6.2 FCAPS Management of Near-RT RIC

The FCAPS management consists of fault, configuration, accounting, performance and security management. The FCAPS management follows O1 related management aspects defined in [4].

To support FCAPS management services, Near-RT RIC provides the following capabilities in the current version of specification:

- Logging: logging is to capture information needed to operate, troubleshoot and report on the performance of the Near-RT RIC platform and its constituent components. Log records may be viewed and consumed directly by users and systems, indexed and loaded into a data storage, and used to compute metrics and generate reports. Near-RT RIC components log events according to a common logging format. Different logs can be generated (e.g., audit log, metrics log, error log and debug log).
- Tracing: tracing mechanisms are needed to monitor the transactions or a workflow. An example subscription workflow can be broken into two traces namely, a subscription request trace followed by a response trace. Individual traces can be analyzed to understand timing latencies as the workflow traverses a particular Near-RT RIC component.
- Metrics collection: metrics for performance and fault management specific to each xApp logic and other internal functions are collected and published for authorized consumer (e.g., SMO). A metrics collection mechanism is needed to collect and report metrics.

6.2.7 Interface Termination

6.2.7.1 E2 Termination

- E2 Termination terminates the SCTP connection from each E2 Node.
- E2 Termination routes messages from the xApps through the SCTP connection to the E2 Node.
- E2 Termination decodes the payload of an incoming ASN.1 message enough to determine message type.
- E2 Termination handles incoming E2 messages related to E2 connectivity.
- E2 Termination receives and respond to the E2 Setup Request from the E2 Node.
- E2 Termination notifies xApps of the list of RAN functions supported by an E2 Node based on information derived from E2 Setup and RIC Service Update procedures [3].
- E2 Termination notifies the newly connected E2 Node of the list of accepted functions.

6.2.7.2 A1 termination

A1 termination provides a generic API for the Near-RT RIC by means of which it can receive and send messages via A1 interface [8]. These include, e.g., A1 policies and enrichment information received from the non-RT RIC, or A1 policy feedback sent towards the non-RT RIC.

6.2.7.3 O1 termination

O1 termination communicates with SMO via O1 interface and exposes O1-related management services [5] from Near-RT RIC.

- O1 termination exposes provisioning management services from Near-RT RIC to O1 provisioning management service consumer.
- O1 termination supports managing xApps via NETCONF.
- O1 termination supports translation of NETCONF to Near-RT RIC internal APIs.
- O1 termination exposes FM services to report faults and events from Near-RT RIC to O1 FM service consumer.
- O1 termination exposes PM services to report bulk and real-time PM data from Near-RT RIC to O1 PM service consumer.
- O1 termination exposes file management services to download ML files, software files, etc. and upload log/trace files.
- O1 termination exposes communication surveillance services to O1 communication surveillance service consumer.

6.3 xApps

xApps consist of xApp descriptor and xApp image. xApp descriptor describes the packaging format of xApp image. xApp image is the software package.

The xApp descriptor provides xApp management services with necessary information for the LCM of xApps, such as deployment, deletion, upgrade etc. The xApp descriptor also provides extra parameters related to the health management of the xApps, such as auto scaling when the load of xApp is too heavy and auto healing when xApp becomes unhealthy. The xApp descriptor provides FCAPS and control parameters to xApps when xApp is launched.

The definition of xApp descriptor includes:

- The basic information of xApp, including name, version, provider, URL of xApp image, virtual resource requirements (e.g. CPU), etc. This information is used to support LCM of xApps.
- The FCAPS management specifications that specify the options of configuration, performance metrics collection, etc. for the xApp.
- The control specifications that specify the data types consumed and provided by the xApp for control capabilities (e.g. PM data that the xApp subscribes, the message type of control messages).

The xApp image contains all the files needed to deploy an xApp. An xApp can have multiple versions of xApp image, which are tagged by the xApp image version number.

7 Open APIs for xApp

7.1 Overall Description of API

Near-RT RIC provides the following open APIs for xApps as showed in Figure 7.1-1:

- A1 related APIs: the APIs between xApps and A1 Termination.
- E2 related APIs: the APIs between xApps and E2 Termination.
- Management APIs: the APIs between xApps and management related functions, such as O1 termination, management services and logging, tracing, metrics collection.
- Control APIs: the APIs between xApps and the functions which are responsible for control, such as conflict mitigation, xApp subscription management, etc.
- SDL APIs: the APIs between xApps and Shared Data Layer.

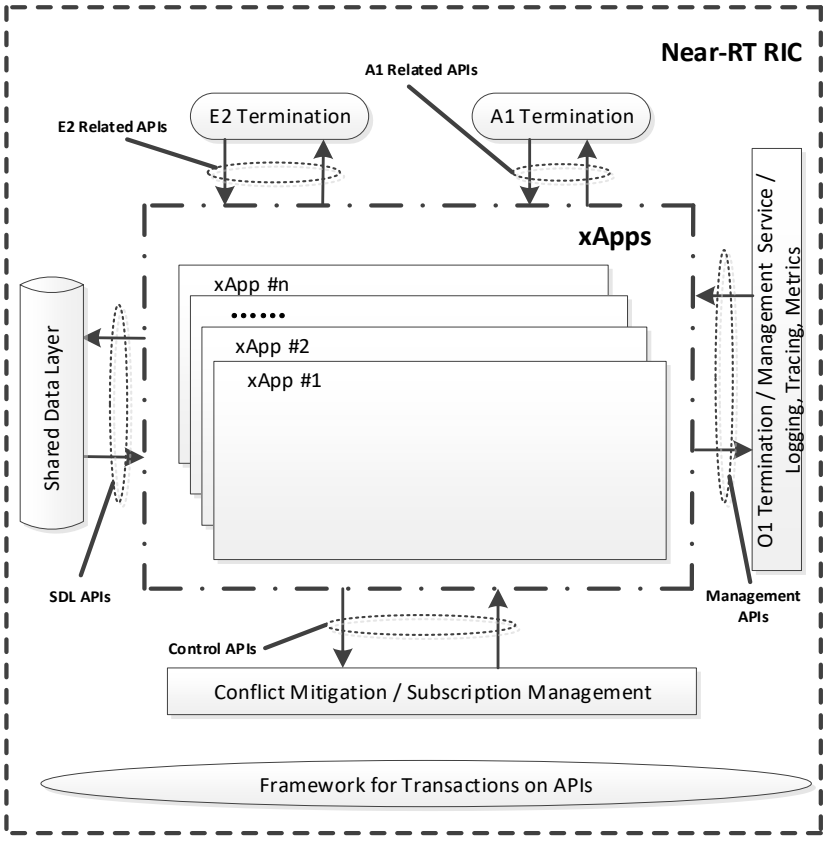

Figure 7.1-1 Overview of Open APIs

7.2 A1 related APIs

The xApps in Near-RT RIC provide value added services based on the policies or enrichment information or both which are transferred through A1 interface by non-RT RIC. A1 related APIs enable the exchange of information between xApps and A1 termination, which includes:

- Policy Enforcement API: used for policy enforcement request/response.

- Enrichment Information API: used for enrichment information transfer/response.

7.3 E2 related APIs

E2 related APIs enable the exchange of information between xApps and E2 termination.

7.4 Management APIs

Management APIs support the following APIs, including xApp life-cycle management related APIs, PM and FM related APIs.

xApp life-cycle management related APIs include the following functions:

- ML Model Deployment Request.
- ML Model Update Request.
- ML Model Uninstall Request.

FCAPS related APIs include the following functions:

- Configuration API: The xApp is configured by SMO via O1 interface. The API transfers the configurations from SMO to xApp.
- PM API: xApps provide PM related data to O1 PM Consumer via PM API.
- FM API xApps provide faults and events information to O1 FM Consumer via FM API.

7.5 Control APIs

The APIs provide the exchange of control related information between xApps and the functions which are responsible for control such as conflict mitigation, xApp subscription management. For example, the analysis results, decisions or requests from xApps can be transferred via the API for conflict mitigation, xApp subscription management or other necessary functions.

7.6 SDL APIs

SDL APIs provide a simple yet flexible way to store and retrieve data while hiding details such as type and location of database, management operations of database layer such as high availability, scaling, load-balancing. SDL APIs allow multiple xApps to access the data independently of each other.

- Register API: xApps can register at SDL for the permissions to access the database.
- Deregister API: xApps can request to delete the API which has been registered in SDL.
- Modify API: It allows to modify or delete data from the database.
- Fetch API: It allows the xApps to fetch data from the database.
- Store API: It allows the xApps to store data in the database.
- Notification API: The database can notify the xApps the update information on the database via the notification API. The database will ignore the notification to the xApp when update occurs if the notification API is not registered by the xApp.

8 External Interfaces of Near-RT RIC

8.1 E2 Interface

O-RAN-WG3.E2GAP [2] specifies E2 interface general aspects and principles.

O-RAN-WG3.E2AP [3] specifies E2 interface application protocols.

8.2 A1 Interface

O-RAN-WG2.A1.GA&P [8] specifies A1 interface general aspects and principles.

O-RAN-WG2.A1AP [9] specifies A1 interface application protocols.

8.3 O1 Interface

O-RAN-WG1.O1-Interface [5] specifies O1 interface related aspects.

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2.2 Adopter shall not use O-RAN Specifications except as expressly set forth in this Agreement or in a separate written agreement with O-RAN Alliance.

Section 3: FRAND LICENSE

3.1 Members, Contributors and Academic Contributors and their Affiliates are prepared to grant based on a separate Patent License Agreement to each Adopter under Fair Reasonable And Non- Discriminatory (FRAND) terms and conditions with or without compensation (royalties) a nonexclusive, non-transferable, irrevocable (but subject to Defensive Suspension), non-sublicensable, worldwide patent license under their Necessary Claims to make, have made, use, import, offer to sell, lease, sell and otherwise distribute Compliant Implementations; provided, however, that such license shall not extend: (a) to any part or function of a product in which a Compliant Implementation is incorporated that is not itself part of the Compliant Implementation; or (b) to any Adopter if that Adopter is not making a reciprocal grant to Members, Contributors and Academic Contributors, as set forth in Section 3.3. For the avoidance of doubt, the foregoing licensing commitment includes the distribution by the Adopter's distributors and the use by the Adopter's customers of such licensed Compliant Implementations.

3.2 Notwithstanding the above, if any Member, Contributor or Academic Contributor, Adopter or their Affiliates has reserved the right to charge a FRAND royalty or other fee for its license of Necessary Claims to Adopter, then Adopter is entitled to charge a FRAND royalty or other fee to such Member, Contributor or Academic Contributor, Adopter and its Affiliates for its license of Necessary Claims to its licensees.

3.3 Adopter, on behalf of itself and its Affiliates, shall be prepared to grant based on a separate Patent License Agreement to each Members, Contributors, Academic Contributors, Adopters and their Affiliates under Fair Reasonable And Non-Discriminatory (FRAND) terms and conditions with or without compensation (royalties) a nonexclusive, non-transferable, irrevocable (but subject to Defensive Suspension), non-sublicensable, worldwide patent license under their Necessary Claims to make, have made, use, import, offer to sell, lease, sell and otherwise distribute Compliant Implementations; provided, however, that such license will not extend: (a) to any part or function of a product in which a Compliant Implementation is incorporated that is not itself part of the Compliant Implementation; or (b) to any Members, Contributors, Academic Contributors, Adopters and their Affiliates that is not making a reciprocal grant to Adopter, as set forth in Section 3.1. For the avoidance of doubt, the foregoing licensing commitment includes the distribution by the Members', Contributors', Academic Contributors', Adopters' and their Affiliates' distributors and the use by the Members', Contributors', Academic Contributors', Adopters' and their Affiliates' customers of such licensed Compliant Implementations.

Section 4: TERM AND TERMINATION

4.1 This Agreement shall remain in force, unless early terminated according to this Section 4.

4.2 O-RAN Alliance on behalf of its Members, Contributors and Academic Contributors may terminate this Agreement if Adopter materially breaches this Agreement and does not cure or is not capable of curing such breach within thirty (30) days after being given notice specifying the breach.

4.3 Sections 1, 3, 5 - 11 of this Agreement shall survive any termination of this Agreement. Under surviving Section 3, after termination of this Agreement, Adopter will continue to grant licenses (a) to entities who become Adopters after the date of termination; and (b) for future versions of O-RAN Specifications that are backwards compatible with the version that was current as of the date of termination.

Section 5: CONFIDENTIALITY

Adopter will use the same care and discretion to avoid disclosure, publication, and dissemination of O-RAN Specifications to third parties, as Adopter employs with its own confidential information, but no less than reasonable care. Any disclosure by Adopter to its Affiliates, contractors and consultants should be subject to an obligation of confidentiality at least as restrictive as those contained in this Section. The foregoing obligation shall not apply to any information which is: (1) rightfully known by Adopter without any limitation on use or disclosure prior to disclosure; (2) publicly available through no fault of Adopter; (3) rightfully received without a duty of confidentiality; (4) disclosed by O-RAN Alliance or a Member, Contributor or Academic Contributor to a third party without a duty of confidentiality on such third party; (5) independently developed by Adopter; (6) disclosed pursuant to the order of a court or other authorized governmental body, or as required by law, provided that Adopter provides reasonable prior written notice to O-RAN Alliance, and cooperates with O-RAN Alliance and/or the applicable Member, Contributor or

Academic Contributor to have the opportunity to oppose any such order; or (7) disclosed by Adopter with O-RAN Alliance's prior written approval.

Section 6: INDEMNIFICATION

Adopter shall indemnify, defend, and hold harmless the O-RAN Alliance, its Members, Contributors or Academic Contributors, and their employees, and agents and their respective successors, heirs and assigns (the "Indemnitees"), against any liability, damage, loss, or expense (including reasonable attorneys' fees and expenses) incurred by or imposed upon any of the Indemnitees in connection with any claims, suits, investigations, actions, demands or judgments arising out of Adopter's use of the licensed O-RAN Specifications or Adopter's commercialization of products that comply with O-RAN Specifications.

Section 7: LIMITATIONS ON LIABILITY; NO WARRANTY

EXCEPT FOR BREACH OF CONFIDENTIALITY, ADOPTER'S BREACH OF SECTION 3, AND ADOPTER'S INDEMNIFICATION OBLIGATIONS, IN NO EVENT SHALL ANY PARTY BE LIABLE TO ANY OTHER PARTY OR THIRD PARTY FOR ANY INDIRECT, SPECIAL, INCIDENTAL, PUNITIVE OR CONSEQUENTIAL DAMAGES RESULTING FROM ITS PERFORMANCE OR NON-PERFORMANCE UNDER THIS AGREEMENT, IN EACH CASE WHETHER UNDER CONTRACT, TORT, WARRANTY, OR OTHERWISE, AND WHETHER OR NOT SUCH PARTY HAD ADVANCE NOTICE OF THE POSSIBILITY OF SUCH DAMAGES. O-RAN SPECIFICATIONS ARE PROVIDED "AS IS" WITH NO WARRANTIES OR CONDITIONS WHATSOEVER, WHETHER EXPRESS, IMPLIED, STATUTORY, OR OTHERWISE. THE O-RAN ALLIANCE AND THE MEMBERS, CONTRIBUTORS OR ACADEMIC CONTRIBUTORS EXPRESSLY DISCLAIM ANY WARRANTY OR CONDITION OF MERCHANTABILITY, SECURITY, SATISFACTORY QUALITY, NONINFRINGEMENT, FITNESS FOR ANY PARTICULAR PURPOSE, ERROR-FREE OPERATION, OR ANY WARRANTY OR CONDITION FOR O-RAN SPECIFICATIONS.

Section 8: ASSIGNMENT

Adopter may not assign the Agreement or any of its rights or obligations under this Agreement or make any grants or other sublicenses to this Agreement, except as expressly authorized hereunder, without having first received the prior, written consent of the O-RAN Alliance, which consent may be withheld in O-RAN Alliance's sole discretion. O-RAN Alliance may freely assign this Agreement.

Section 9: THIRD-PARTY BENEFICIARY RIGHTS

Adopter acknowledges and agrees that Members, Contributors and Academic Contributors (including future Members, Contributors and Academic Contributors) are entitled to rights as a third-party beneficiary under this Agreement, including as licensees under Section 3.

Section 10: BINDING ON AFFILIATES

Execution of this Agreement by Adopter in its capacity as a legal entity or association constitutes that legal entity's or association's agreement that its Affiliates are likewise bound to the obligations that are applicable to Adopter hereunder and are also entitled to the benefits of the rights of Adopter hereunder.

Section 11: GENERAL

This Agreement is governed by the laws of Germany without regard to its conflict or choice of law provisions.

This Agreement constitutes the entire agreement between the parties as to its express subject matter and expressly supersedes and replaces any prior or contemporaneous agreements between the parties, whether written or oral, relating to the subject matter of this Agreement.

Adopter, on behalf of itself and its Affiliates, agrees to comply at all times with all applicable laws, rules and regulations with respect to its and its Affiliates' performance under this Agreement, including without limitation, export control and antitrust laws. Without limiting the generality of the foregoing, Adopter acknowledges that this Agreement prohibits any communication that would violate the antitrust laws.

By execution hereof, no form of any partnership, joint venture or other special relationship is created between Adopter, or O-RAN Alliance or its Members, Contributors or Academic Contributors. Except as expressly set forth in this Agreement, no party is authorized to make any commitment on behalf of Adopter, or O-RAN Alliance or its Members, Contributors or Academic Contributors.

In the event that any provision of this Agreement conflicts with governing law or if any provision is held to be null, void or otherwise ineffective or invalid by a court of competent jurisdiction, (i) such provisions will be deemed stricken from the contract, and (ii) the remaining terms, provisions, covenants and restrictions of this Agreement will remain in full force and effect.

Any failure by a party or third party beneficiary to insist upon or enforce performance by another party of any of the provisions of this Agreement or to exercise any rights or remedies under this Agreement or otherwise by law shall not be construed as a waiver or relinquishment to any extent of the other parties' or third party beneficiary's right to assert or rely upon any such provision, right or remedy in that or any other instance; rather the same shall be and remain in full force and effect.