On O-RAN, MEC, SON and Network Slicing integration

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***Abstract*—A concept of O-RAN with MEC, SON and Network Slicing integration is presented in the paper. The O-RAN platform is proposed as a common denominator for the integration of the mentioned technologies via proper modifications and extensions of its present architecture. Due to the proposed integration, several redundant components can be eliminated and some synergies can be achieved. We have described the key features of the integrated technologies and also pointed out the benefits of their integration. We have outlined the O-RAN-centric way in which the solutions are integrated as well. As the work on 5G Network Slicing with MEC integration is still progressing in 3GPP and in the O-RAN Alliance, the paper can be seen as indication of future works. According to our best knowledge, the presented approach is the first one that aims to integrate the mentioned technologies.**

***Index Terms*—5G, O-RAN, network slicing, MEC, SON**

I. Introduction

The deployment of 5G mobile networks is ongoing. In most countries the so-called Non-Standalone 5G networks (NSA) are deployed so far. This variant of 5G lies on the integration of 4G RAN with 5G RAN and modification of the 4G Core Network (EPC) to enable interworking with 5G RAN nodes. To support elevated requirements for high density devices (e.g. Smart Cities), very low latency (e.g. Industry 4.0) or high bandwidth (e.g. virtual reality) the 5G Stand-Alone (SA) variant has been introduced. 5G SA enables programmability of Control Plane (CP) of 5G Core (5GC) and supports Network Slicing (NS) in both parts of the network. The programmability of the 5GC CP allows the creation of context- or service-aware CP operations and NS enables the creation of multiple, service-aware network slices, both having User Plane (UP) and CP operations tailored for a specific service. Such an approach is viable due to the usage of network virtualization concept (ETSI NFV MANO-based), which allows the dynamic creation of separate logical networks on the shared infrastructure. 3GPP has defined three Slice Service Types after ITU-R vision [1]: Ultra-Reliable Low Latency (URLLC), Enhanced Mobile Broadband (eMBB) and Massive Machine Type Communication (mMTC) and recently the additional type for V2X communications, all supported by specialized functions and mechanisms (i.a. NSSF) [2]. The 3GPP has defined basic principles concerning NR (New Radio) slicing (so far RAN UP operations only) in [3]. The O-RAN Alliance [4] is working on a programmable solution that automates NR operations and makes the RAN aware of the application needs at the same time. However, so far, NS is not well addressed yet by the O-RAN Alliance. The RAN automation in the 4G network has been provided by the LTE-SON concept that is an implementation of the feedback loop-based real-time management using dedicated servers [5]. Unfortunately, the 5G-SON development is at the early stage. Yet another noteworthy concept is the Multi-access Edge Cloud (MEC), which primary role is shortening the data paths to minimize the communication latency and optimize data traffic distribution by dynamically deploying applications closer to the edge. MEC also facilitates exploitation and provision of RAN and User Equipment (UE) related information via APIs. Whereas MEC is already well-defined for 4G networks, its integration with the 5G network, especially with NS, is still in progress [6]. The analysis of O-RAN, MEC, SON and NS approaches has shown that these technologies are both, partly complementary and partly overlapping. Moreover, some mechanisms developed within one solution can be efficiently reused by others. This observation is a motivation of this paper in which an integrated concept of O-RAN, MEC, SON and NS has been presented. The focus has been laid on O-RAN and providing extensions to its existing architecture, which so far is not complete and does not support SON, MEC or NS.

II. Subsystems to be integrated

Below provided is the essential information about the systems to be integrated with focus on similarities and complementarities.

A. O-RAN

The O-RAN approach (developed by the O-RAN Alliance [4]) is an open source platform for building management and control of 5G RAN (NR) with generic IT hardware and standardized interfaces. The concept lies on adding some functional elements to the architecture while conforming the 3GPP standards and also to propose extensions required by O-RAN functionalities. The activity of the O-RAN Alliance is twofold. The first area of activity of the consortium is related to O-RAN specifications. The second one deals with the open source implementation of the concept by O-RAN Software Community [7]. The access to O-RAN specifications is free, but it requires prior admission. Unfortunately, the O-RAN Alliance requires the specification to be kept confidential and they cannot be cited. The interested reader can, however, contribute to the project. The below description is based on publicly available information – presentations of O-RAN Alliance members, non-confidential documents available at O-RAN website and O-RAN Software Community wiki.

1) O-RAN goals: The list of O-RAN use cases include cross-layer traffic steering, QoE optimization, V2X proactive handover support (position prediction using navigation data), flight path-based dynamic UAV resource allocation, RAN energy saving and energy-aware IoT operations, cross-layer RAN optimization, MIMO beam-forming optimization, and automation of RAN operations. The key idea of the concept is to adapt the Radio Resource Management (RRM) operations (admission control, mobility management, radio link management, advanced SON functions, etc.) according to applications' needs [8]. Due to the collecting of monitoring data concerning UEs and network, the concept should enable prediction of QoE, mobility pattern, cell traffic, network quality and users' distribution.

2) O-RAN architecture: The O-RAN specifications have introduced the near-Real Time RAN Intelligent Controller (near-RT RIC) that interacts with RAN nodes (CU, DU) using O-RAN specific E2 interface. The interface is used for feedback loop-based RAN nodes control. The approach requires collecting of fine-grained monitoring data and implementation of the decision engines that will be responsible for taking required actions. This RIC provides RRM functionalities with embedded intelligence. It enhances original RRM functionalities such as per-UE controlled load-balancing, interference detection and mitigation, etc. The used gNB split is 7-2x (work on other splits is in progress). The reaction time of near-RT RIC is specified to be in the range of 10 ms – 100 ms. It allows for deployment of near-RT RIC applications (called xApps) that may use 2 near-RT RIC databases, one consisting of information about UEs (UE-NIB) and another one consisting of information about RAN nodes (R-NIB). The near-RT RIC has component for mitigation of conflicts caused by xApps requests. It also contains a library of functions supporting AI-driven operations (model repository, inference). The near-RT RIC contains a library of functions supporting AI-driven operations (model repository, inference) and each xApp may subscribe to the relevant parameters.

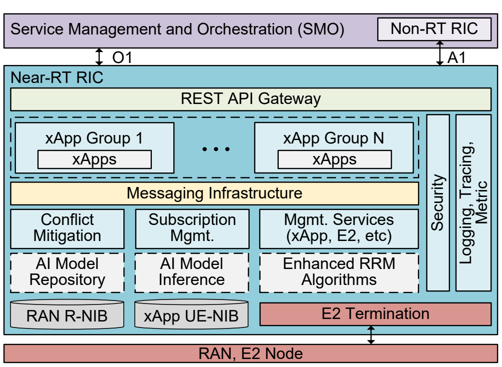

Fig. 1: O-RAN reference architecture [9]

The near-RT RIC interacts with the RAN management system (i.e. OSS/BSS), which sometimes in the documents is referred to a non-Real Time RIC (non-RT RIC). The main functionality of the non-RT RIC is service and policy management, RAN analytics and model training for the near-RT RAN functionalities, essential for near-RT RIC run-time execution. The ONAP platform [10] is seen as OSS/BSS. ONAP functionalities important for O-RAN include orchestration of applications and the ability of control loop-based operations. In contrast to near-RT RIC, the control loop-based operations of non-RT RIC are much slower and typically used for semi-static, intent-based management operations via the A1 interface (reaction time $>> 1$ s) for non real-time management, e.g. inventory/policy/configuration management. In some drafts, the non-RT RIC is responsible for SON operations. Another interface between the management system and near-RT RIC, named O1, is used for orchestration of xApps. The near-RT RIC can handle multiple RAN nodes, but no interface between near-RT RICs has been defined yet. The O-RAN framework enables the implementation of RAN components in cloud environments. In such case O1 supports typical FCAPS and Service Management and Orchestration and additional interface, i.e. O2 is specified for support of virtual resource management and other, cloud-related management functions.

3) O-RAN open issues: The work on O-RAN specification is still in progress and it seems that still exist some gaps in the concepts that have to be solved yet:

– The O-RAN near-RT RIC has a component responsible for the coordination of multiple requests, but there is still lack of details. Moreover, delayed system response may lead to unstable behaviour of nodes controlled by the near-RT RIC, in some situations several iterations are needed to achieve the goal. This may increase the system response time and in result a ping-effect can be observed. This problem is not addressed by O-RAN.

– Cooperation of multiple near-RT RICs is not provided. It can be realized via the peer-to-peer interface – the work on such interface (marked Y2) is in progress. The preferred solution in order to handle users mobility between the RICs is the stateless approach, but if it is not implemented, the state context has to be exchanged between RICs.

– So far, there are no restrictions to access R-NIB and UE-NIB databases by xApps. It raises isolation and security concerns. A creator of xApp is able to implement gathering of confidential information (associated with network operator or other xApps) about cells or UEs status (load, positions, etc.).

– It is necessary to define, which UE is used with which xApp. Such assignment has to be done at the UE level. It is not specified how to make it.

– The O-RAN Alliance has started to work on O-RAN and NS integration, but the work is at the early stage, yet.

– The Self-Organizing Network (SON) concept that provides 4G RAN management automation (self-configuration, self-healing and self-optimization) can and should be implemented in O-RAN. So far such possibility has been identified in O-RAN but not defined in details.

– The O-RAN services do not interact so far with 5GC CP, so end-to-end O-RAN – 5GC services cannot be created.

Despite nonexistence of important mechanisms, the O-RAN concept seems to be the most promising one in terms of service-aware automated RAN and end-to-end operations.

B. SON

1) SON goals: Self Organizing Network (SON) provides 4G and 5G RAN management automation [5], that includes self-configuration of newly deployed base stations, performance optimization and fault management. Self-optimization mechanisms concern coverage, capacity, handover, QoS, energy consumption and interference control. Self-healing includes automatic detection and mitigation of failures. List of SON functions (use cases) has been described by the 3GPP. SON is based on feedback loops; therefore, for its implementation, it is necessary to monitor RAN and reconfigure it in near real-time on that basis. The list of SON functions has been defined for LTE, for 5G RAN (NR) the work is still in progress – some of the 5G-SON services and related procedures have already been defined.

2) SON architecture: There is no detailed architecture of SON provided by 3GPP. In general, it is assumed that SON is a part of the management system (OAM); however, its implementation allows for distribution of SON functions. It is assumed that the OAM system provides to SON relevant measurements, information about alerts, and allows the SON to reconfigure network nodes or functions [5]. In 4G the NM-Centralized SON is implemented as a part of the network management system (i.e. OSS/BSS), in EM-Centralized SON, the SON algorithms are executed at the Element Management level. According to [11], 5G SON algorithms can operate on different levels of the network: (i) in the Cross-Domain Layer (ii) in the Domain Layer and (iii) at the Network Function Layer. Accordingly, four types of SON are distinguished: Cross Domain-Centralized SON (C-SON) and Domain-Centralized SON that both execute in the management system and the Distributed SON (D-SON) located in the Network Function layer. SON can use the Management Data Analytics Service (MDAS) [12]. It is expected that SON will also operate in 5GC and address the NS (resource allocation optimization, collecting slice relevant data, solving inter-slice issues, etc.), but the work is still in progress, however.

3) SON issues: Despite the standardization efforts, the deployed SON solutions are vendor-specific and not interoperable. One of the issues with SON is lack of detailed implementation architecture and interfaces. Neither SON monitoring database, nor ways of SON functions conflicts resolutions have been defined. So far, the SON concept does not use the NFV paradigm and orchestration of SON functions and is only mentioned in O-RAN documents.

C. MEC

1) MEC goals: Multi-access Edge Computing (MEC) by ETSI is dedicated to standardization of an open environment for integration of various applications across multi-vendor computing platforms tightly integrated with the multi-technology RAN. The synergy of IT and telco worlds at the edge of the communication network gives numerous benefits related to re-shaping the overall use case-related architecture, i.e. locating the applications near the customer, receiving contextual information from RAN as well as optimizing the traffic distribution, resources utilization and network performance. MEC hosts applications and services (Layer 4 and above) "on top" of the RAN controller or even the base station.

2) MEC architecture: Within the MEC architecture [13], two major parts can be distinguished: MEC system level comprised of OSS, applications/infrastructure orchestration entities and application life cycle management API proxy, and MEC host level consisting of MEC Platform that hosts MEC applications and exposes API to them, MEC Platform Manager responsible for the management of platform itself as well as applications life cycle, Virtualization Infrastructure and its Manager and finally the underlying network (e.g. local, external or 3GPP network). The fundamental mechanisms of MEC are: (i) seamless inter-platform application mobility, platform services APIs for i.a. users location and radio conditions contexts exposure, (ii) underlying data network traffic steering for selective applications-related data redirection or (iii) application implementation and orchestration.

3) MEC issues: The architectural framework allows for MEC implementation without or with NFV. The concept was developed for the 4G network; hence, it is not well integrated with 5G and NS, yet. MEC platform APIs expose RAN data to MEC applications; however, in contrast to O-RAN, MEC is unable to influence the RAN configuration.

D. Network slicing

1) Network slicing goals: NS provides the capability of dynamic creation of logically isolated, service-customized networking solutions using common infrastructure. The concept is a part of the 5G network definition and allows for the creation of multiple instances of pre-defined slice types (eMBB, mMTC, URLLC, V2X). Despite being an end-to-end functionality, to form an end-to-end slice, the sub-network slices, i.e. NR slice and 5GC have to be stitched together. NS concerns both UP and CP. Slice isolation should ensure a lack of impact of the congestion of one slice on UP QoS of other slices. Moreover, the management operations can be performed by the slice operator (tenant).

2) Network slicing architecture: NS is founded on the ETSI NFV MANO approach [14]. In 5G, NS is supported by several unsliceable CP's components responsible for selection (NSSI) or slice authentication (UDM). OSS/BSS system is responsible for network slices as well as life-cycle (orchestration) and run-time management [2], which has a key importance for NS. The NR is aware of the existence of network slices, provides isolated data transmission paths, but it is not virtualized. In case of RAN slicing the 3GPP specification allows for different implementation (Layer 1, Layer 2, MAC-based). Currently, the most popular NS implementation at RAN is based on scheduling of Physical Resource Blocks (PRB) – i.e. time-frequency blocks, which size and duration follow the 5G numerology (frequency raster and transmit time interval). In case of slicing, the scheduler should work on both slice and user level. The slice level scheduling should provide isolation between slices. NR slice is offered as a kind of VPN and is provided via API – it is described by its type

(SST) and related attributes. The mechanisms defined by 3GPP, as punctured preemptive scheduling (mini-slots) in the downlink [15], grant free access in uplink [16] or other RAN slicing supporting mechanisms, e.g. RAN functional split or joint routing mechanisms [17] enable more efficient resources exploitation. In general, NR slicing should use Radio Resource Management (RRM) functions, i.e. spectrum planning, Inter-Cell Interference Coordination (ICIC) or Admission Control (AC) as described in [18].

3) Open issues in NR slicing: So far, NS concerns mostly UP mechanisms. A list of NR slicing issues can be found in [19]. The most popular approach of RAN slicing, based on PRB scheduler, raises performance issues in case of a huge number of URLLC slices (low delay can be hard to achieve). Currently, there are many commercial 5G SA networks, but none of them supports NS yet.

III. O-RAN, MEC, SON and Network Slicing Integration Concept

The presented analysis of O-RAN, SON, MEC and NS shows overlaps and complementarities between them. Their proper integration with a new decomposition can bring essential benefits it terms of removal of redundant functional blocks and providing overall synergy. However, a new functional decomposition is required to reduce the overall complexity and allow for cross-layer operations. It is also noteworthy that non-integrated implementation of the analyzed system may lead to conflicting decisions able to degrade system performance. For example, the MEC platform may adapt the MEC application to NR conditions (without impact on the NR behaviour). At the same time, the O-RAN may try to adapt NR to the application needs. The analysis of the technologies presented in Section II has led us to the following conclusions regarding the benefits of their mutual integration:

1) SON and O-RAN integration: The benefits of integration lie on the usage of the same servers (hosts or edge data center), monitoring databases and the ability of cross-operations – the SON decisions can be re-used by xApps. The SON functions can be implemented as semi-permanent xApps, which interact with other xApps exposing their information and services. They implement the operator's, not services' goals.

2) MEC and O-RAN integration: MEC hosts can be combined with the near-RT RIC hosts and the MEC-based CP services can be O-RAN services. MEC databases (about UE locations, cell performance, RNIS) can be integrated with O-RAN databases and the MEAO can be used for xApps orchestration as it provides application mobility. This mechanism should be reused in multi-near-RT RIC environment, solving an essential problem of the inter-near-RT RICs cooperation. Each near-RT RIC/MEC hosts or edge data center should contain the MEC Platform (MEP) where MEAO can also orchestrate MEC UP functions.

3) Network Slicing and O-RAN integration: The NS is the missing feature of O-RAN. It impacts O-RAN in several ways. First, the slice xApps have to be defined in NR slice template (a new feature, currently absent in 3GPP NR slicing). Second, each slice needs a separate partition of the database containing information about the NR nodes and attached UEs. These partitions should also keep information about slice-level KPIs/KQIs. Third, the UE attachment to slices, in line with 3GPP specifications, can be done by NSSF and UDM as defined in [2]. The NS approach solves the problem of individual UE handling by near-RT RIC and security issues. The E2 interface has to be modified to support NS by the PRB scheduler. The end-to-slice template should define the interactions between NR xApps with the 5GC sub-network slice counterparts, solving that way lack of cooperation between O-RAN (xApps) and 5GC. The CU/DU nodes should be modified to support NS.

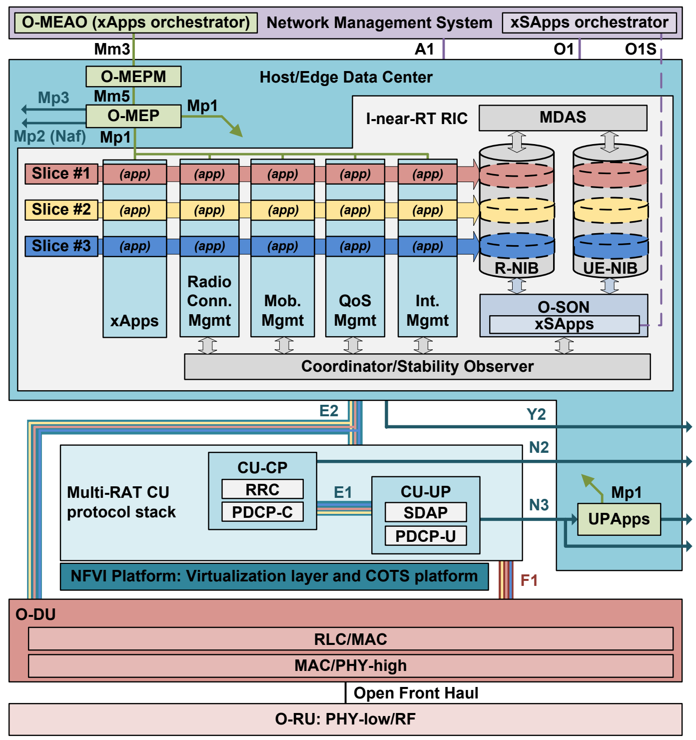

Fig. 2: The integrated O-RAN, SON, MEC platform showing internal components of the I-near-RT RIC

A new architecture that integrates the mentioned technologies is presented in Fig. 2. As already stated, we assume immersive integration of several technologies, but for the clarity of the description, the terminology introduced by these technologies will be used. We propose to use the same host (or edge cloud) for the virtualized implementation of integrated and modified near-RT RIC, SON, MEC and NS functions called "Integrated near-RT RIC" (I-near-RT RIC). We assume that the communication within the I-near-RT RIC will be provided via a message bus, hence no interactions between the components of the RIC need to be described. The most shared components of the architecture are two databases: (i) R-NIB with information about the NR nodes and (ii) UE-NIB with information about all UEs in the area served by the I-near-RT RIC (both databases' names follow O-RAN terminology). The information stored in both databases is used by the Management Data Analytics Service (MDAS) component that provides data analytics and predictions as defined in [20], also at the NR slice level. It is assumed that the MEP API interfaces to both databases are provided (i.e. RNIS, LS).

The R-NIB, UE-NIB and MDAS information is used by the mboxO-SON functions – “xSApps” (SON-dedicated xApps) installed in all I-near-RT RICs (a distributed SON approach), using the orchestrator. Their goal is NR management automation, as defined by 3GPP. The SON functions can be dynamically deployed/updated. They interact with non-RT RIC for policy-based management. The non-RT RIC is responsible for communication between SON components of I-near-RT RICs (if needed). The xSApps can also expose their APIs to xApps for sharing the NR nodes’ status (e.g. failure) or management policy preferences. O-SON is also responsible for resource allocation to slices. All xApps and xSApps reconfiguration requests are going through the Coordinator/Stability Observer component. Its role is to resolve requests’ conflicts based on priorities, but also to observe the system stability by monitoring variance of predefined KPIs, and if necessary to restore the last stable configuration. Moreover, the component identifies troublesome xApps/xSApps and alerts the non-RT RIC, which can decide to stop them. The Coordinator component is already defined in near-RT RIC, but its combination with the Stability Observer is missing.

The implementation of NS alters the near-RT RIC architecture and O-RAN interfaces’ functionality, but also solves some of the O-RAN issues. Firstly, using slice-allocated xApps, enables advanced operation of NR on per slice level as defined in O-RAN specifications – the NR is no more only a set of pipes of differentiated QoS (e.g. eMBB, URLLC). It also provides differentiation of i.a. mobility-related operations. Secondly, the use of NS provides the interaction between 5GC (sub-)network slice and NR (sub-)network slice using native 5GC NS-related and already defined mechanisms. Using them, both sub-network slices can be stitched together, while user authentication and slice selection can be done as already defined by 3GPP [2]. An important novelty is the existence of VNFs in NR on a slice level. This changes the way in which end-to-end 5G slices should be orchestrated. The concept of integration of NR sub-network slices with 5GC sub-network slice in case of two I-near-RT RICs is shown in Fig. 3. In the figure, only those components of 5GC and NMS are marked that are essential for NS runtime operations. In the proposed concept, the I-near-RT RIC functions are sliced in a way in which all its functional elements are partitioned, and each slice has its own full constellation of these partitions, forming the “virtual RIC” dedicated to the slice. Each xApp deployed in I-near-RT RIC belongs to a slice, and the subscription rules (access to databases), customized MDAS functions and policies related to resource allocations have to be enforced for the slice. The xApps are piggy-backed to the main component that realizes the function, e.g. Main Mobility Management Application. NS requires modification of MAC in order to support scheduling of different traffic types (eMBB, URLLC, etc.), including mini-slot and grant-free access mechanisms for support of non-scheduled URLLC transmissions, customization of the RRM to obtain per slice behaviour as a complementary mechanism to the scheduler that shares the radio link between different applications according to their SLA, using of R-NIB and slice information in order to proactively provide appropriate radio coverage and radio link quality on a per slice type level. The E2 interface can be used for NS information exchange with other nodes (CU/DU). Other interfaces i.e. between the components of 5GC, RAN or MEC, are compliant with their original definitions presented within ETSI or 3GPP normative documents. The detailed specification of the implementation of RRM mechanisms for NS is out of the scope of the paper.

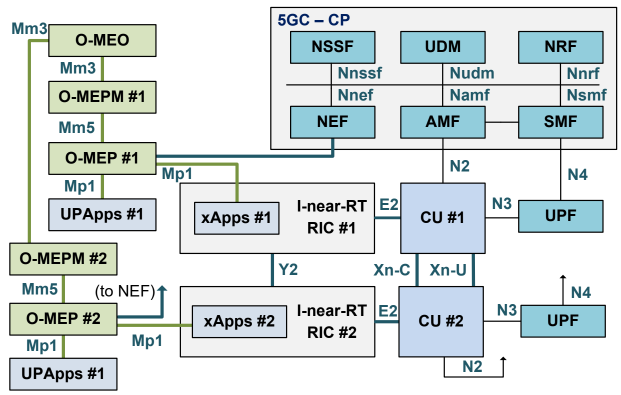

Fig. 3: Overview of integrated O-RAN, 5GC-CP and MEC for two I-near-RT RIC domains

The 3GPP has already specified the management system (NMS) role in NS [21]. The operations of NMS have to be altered to cope with the NR components virtualization. So far, only I-near-RT RIC was assumed to be implemented in a virtualized manner, but CU and DU components can be virtualized as well. The use of SON decentralizes the management operations and simplifies the NMS.

The I-near-RT RIC implements MEC services in a different way that is described in 3GPP specifications. It is worth recalling that the work on the integration of NFV-based MEC for 5G networks is still ongoing, however. In our concept, the CP MEC applications are directly implemented just as xApps. MEP is integrated with 5GC CP through the Mp2 interface (as a specific Application Function); hence, it is seen as Naf by the 5G CP. MEC is decomposed and the core part is called “O-MEP”. The MEP APIs are now provided by the R-NIB and UE-NIB databases. Moreover, MEC xApps may use data analytics services offered by MDAS. The VNFM functionality provided by MEAO is not needed, as it can be provided by the non-RT RIC. The application mobility mechanism of MEC is essential in our concept for slice-level peer-to-peer communication between I-near-RT RICs to provide UE mobility support by migration of slice-level xApps to another I-near-RT RIC or UE context transfer. It is provided by the modified MEC orchestrator (MEAO) called (O-MEO).

The MEC concept brings a significant disruption to the O-RAN architecture regarding UP functions orchestration. Using the mechanisms, L4-L7 operations can be also programmed providing the well-known benefits of MEC related to traffic redirection and application-level processing by the

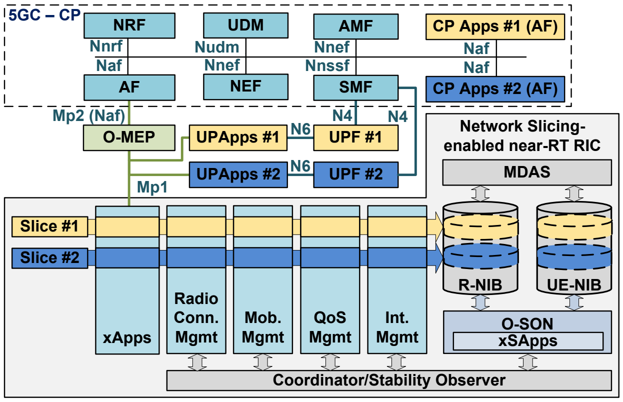

Fig. 4: Overview of two end-to-end slices deployed within one I-near-RT RIC domain

edge-based application server. In contrast to O-RAN xApps, UP applications (UPApps) can handle the UP traffic. However, in some cases, to implement MEC-like services a tandem of xApp and UPApp is required as the access to I-near-RT RIC databases and mechanisms and at the same time the UP processing of user data is needed. The interface between both components does not need to be defined as it is application-specific. In Fig. 4 we have shown a case of two slices with CP (xApp) and UP RAN (UPApp) applications. The figure also shows integration of the slices with 5GC. Due to the incorporation of modified MEC within the architecture, the communication between the applications belonging to the same an end-to-end slice (xApps, CPApps, UPApps) can be established by using Mp1 and Mp2 (Naf) interfaces.

IV. Conclusions

In the paper, we have described O-RAN, SON, MEC and network slicing technologies, emphasizing synergies between them, but also identifying overlapping components of their architectures. Based on the analysis presented in Section II, the integration concept of these technologies, which heart is the I-near-RT RIC, has been presented. We have shown that O-RAN-centric approach is beneficial and such integration solves some of the issues not well-addressed by O-RAN yet. As we have shown, due to the integration, some components of the contributory technologies can be removed or be reused.

Naturally, the presented concept is a very high level one, as it concerns the integration of very complex and not yet fully specified systems. However, we deeply believe that it will blaze the trail of technological integration as its potential benefits are indisputable. The work on the paper has suffered due to the confidentiality of O-RAN specification. We hope that the O-RAN Alliance policy will be changed in the nearest future, thus attracting more scientists interested in the evolution of the O-RAN approach.

Acknowledgment

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