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Challenges and Lessons Learned During Private 5G Open RAN Deployments

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***Abstract*— Cellular systems were standardised and got open through different specified interfaces, but one major part of this system, the RAN (Radio Access Network) stayed quite closed and very much proprietary until now. RAN would probably continue being closed and proprietary for an unforeseeable future if it wasn't down to the mobile operators who want a more diverse ecosystem of vendors and are redefining their requirements for the network architecture.**

The idea of opening RAN has been around for quite some time, since 2002 or even earlier with the creation of an initiative called OBSAI (Open Base Station Architecture Initiative) and CPRI (Common Public Radio Interface), which at the end did not go very far in terms of openness, but a new initiative mainly driven by the mobile operators through O-RAN Alliance founded in 2018 with the intention to break the vendor lock-in, has attracted a lot of attention among the mobile industry players and has led to a number of trials and testbeds globally. These Open RAN testbeds were built and more are being built with an intention to facilitate a commercially-neutral, collaborative environment for testing interoperability and integration of a multi-vendor open RAN architecture.

This paper describes the main challenges and the lessons learned during real deployments of private 5G Open RAN networks done by academia and the industry.

Keywords*— *Open RAN, O-RAN, 5G, Distributed Unit, Central Unit, Radio Unit, RIC, Open RAN Testbed

I. INTRODUCTION

Open RAN is a key enabler that supports the 5G vision to create an optimized end-to-end solutions by facilitating a full range of diverse, 5G RAN application-driven deployments.

Open RAN is not a technology, but it is more an ongoing rearrangement in mobile network architecture to allow the build of new networks using disaggregated RAN elements from different vendors.

The key concept of Open RAN is its openness and full decomposition of key RAN protocols and interfaces between different disaggregated elements. This disaggregation will lead to increased network agility and flexibility, increased innovation and cost savings and will also prevent vendor lock-in.

Currently, the focus of the industry and academia at this time is mainly on protocols and interfaces between RU, DU and CU and between RIC and DU/CU respectively at a later stage as RIC and related apps mature. However, RIC will get full attention gradually as it is seen as the key driver for Open RAN deployment and adoption.

Despite all the advantages that Open RAN is expected to bring, this openness adds to the complexity and the in-house deployment becomes very challenging. This is where the role of System Integration becomes central in making these end-to-end solutions work.

The focus of this paper is on the challenges and lessons learned derived from a number of real deployments and testbeds globally. Some of these well-known testbeds are Vodafone's global Open RAN Test and Validation Lab, NEC Open RAN Testbed in Japan, IBM's Open RAN Testbed jointly with Airspan in Munich, Germany and the IBM's Global Industry Solution Center (GISC) in Nice, France and SONIC Labs, a UK government-funded project jointly with Digital Catapult in London.

In addition, this paper will also describe the architecture of Open RAN, some test cases and test approaches.

First author of this paper is directly involved in SONIC Labs, and hence brings the first-hand experience and lessons learned to this paper, however the experience and knowledge gathered and described in this paper does not focus on SONIC Labs only. The knowledge and experience gathered in this paper is also derived through different contacts and communications from a number of other similar Open RAN Testbeds.

II. WHAT IS OPEN RAN?

To understand Open RAN, we should first describe what traditional or monolithic RAN in Cellular Systems is. RAN is part of a mobile telecommunication system that provides the critical connectivity between the users and mobile networks over radio waves. It also acts as a bridge to access all the key applications on the Web. Unlike traditional RAN provided from a single supplier as a hardware and software traditional platform, Open RAN is provided by multi-suppliers as a separated platform between hardware and software with open interfaces and virtualisation hosted either on the Cloud or on-premise. These open interfaces ensure interoperability between each Open RAN components. This means operators have the possibility to choose the best solution providers for each component knowing that these different components will work together and the rest of the network.

The openness of RAN is also part of the evolution and trend of network element hardware and software separation, which again means utilization of multi-vendor products and solutions in a common hardware infrastructure, also known as COTS (commercial off-the-shelf), and operation and management of this hardware infrastructure through the software in a more efficient way [1].

This approach and added flexibility will allow the operators to become more software-oriented and as such offering better features and services faster, simpler and more cost efficiently.

A. Open RAN building blocks

The Open RAN is made up of the following building blocks:

- The Radio unit (RU)
  - It is a hardware and software unit where the radio frequency signals are transmitted, received, amplified, and digitized, the same as RRU/RRH (Remote Radio Unit/Head) in 4G/5G radio unit
  - The RU is located near or integrated into the antenna
- The Distributed unit (DU)
  - The DU is the computation part of the base station, sending the digitalized radio signal into the network through the CU
  - The DU is physically located at or near the RU
- The Central unit (CU)
  - The CU is also the computation part of the base station, sending the received digitalized radio signal from the DU into the network
  - The CU can be located nearer the Core
- The RIC (RAN Intelligent Controller)
  - A new network element that enables new services added to radio networks, such as software to optimize the performance
  - RIC works by exposing an **API** that lets software talk to each other

III. OPEN RAN ARCHITECTURE

A general view of Open RAN architecture shown below, in figure 1, is defined by O-RAN and is based on enhanced 3GPP functions, layers and interfaces [2],[3],[4].

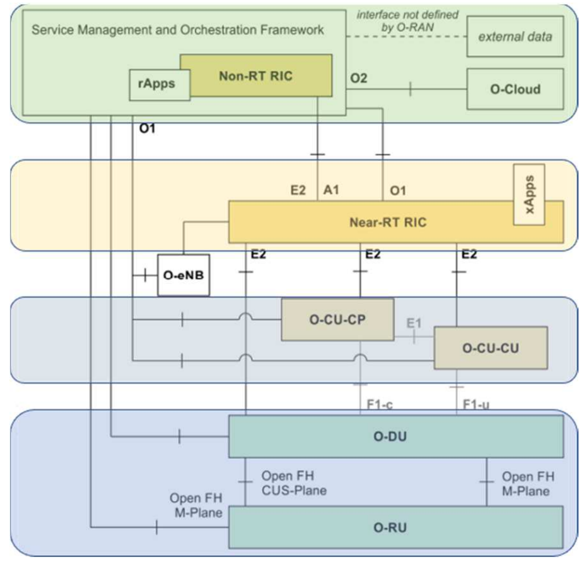

Fig. 1. Open RAN Reference Architecture (adapted), Source: O-RAN Alliance, July 2021

This architecture is composed of the following functional blocks and interfaces:

- Orchestration/NMS layer with Non-Real Time RIC functional layer (SMO-Service Management and Orchestration)
- Near-Real Time RIC function layer
- Multi-RAT CU protocol Function
- DU Functions
- RU Functions
- Interfaces: Fronthaul (FH), F1, A1, E1, O1 and O2

A. Orchestration/NMS layer with Non-Real Time RIC functional layer

This functional layer is outside RAN and comprises SMO (Service Management and Orchestration) and non-real-time RIC as well as rApps.

The SMO is responsible for RAN management and the key capabilities of SMO are:

- Non real-time RIC for optimization
- O-Cloud management, orchestration and traffic management
- Performance management through FCAPS interface to O-RAN network functions

The SMO performs these services through interfaces A1, O1, O2 and Open FH M-plane as shown in figure 1 above.

Non real-time RIC as part of this functional layer is decoupled from near-real-time RIC which is part of a separate functional layer. This decoupling of RIC is used to feed the RIC with contextual data which could be used for different purposes, such as RAN optimization, policy management, RAN analytics etc. Non-real-time RIC handles the control functions within less time constraints, i.e. >1 s, while near real-time RIC handles the control functions that are subject to more time-constraints, i.e. <1 s.

B. Near-real-time RIC functional layer

Near-real-time RIC is a logical function that enables radio resource management optimization using the detailed information received from non-real-time RIC and other functions. This function also hosts one or more xApps, which are dedicated applications to perform different microservices.

As indicated in the previous section, near real-time RIC operates within stricter time constraints, <1 s, or more specifically, within the range of tens of ms.

Some of the key functions managed by this functional layer are:

- QoS management
- connectivity management and
- seamless handover

Furthermore, near real-time RIC receives an AI (Artificial Intelligence) model from non-real-time RIC and executes it to change the functional behavior of the network.

C. Open RAN Central Unit (O-CU)

Central unit is a function that can be deployed on a virtualised platform to provide a highly-efficient execution environment for CU and near-real-time RIC used to distribute capacity across multiple network elements with security isolation, virtual resource allocation, resource encapsulation etc.

Central unit is made up of control plane (O-CU-CP) and user plane (O-CU-UP):

- O-CU-CP is an enhanced version of 3GPP CU-CP that hosts RRC (Radio Resource Control) and control part of PDCP (Packet Data Convergence Protocol) protocols
- O-CU-UP is an enhanced version of 3GPP CU-UP that hosts SDAP (Service Data Adaptation Protocol) and user part of PDCP protocols

D. Open RAN Distributed Unit (O-DU)

Like O-CU, this is another software-based function that can be deployed on a virtualised platform and which hosts RLC (Radio Link Control) and MAC (Medium Access Control) protocols and High-Phy layer. This function includes a subset of the eNB/gNB functions, depending on the functional split option, and its operation is controlled by the O-CU.

E. Open RAN Radio Unit (O-RU)

It is a logical node that hosts Low-Phy and RF processing and which handles the digital front end and the parts of the PHY layer, as well as the digital beamforming functionality.

IV. BENEFITS OF OPEN RAN

There is no doubt about the complexity that Open RAN adds and in particular when it comes to the integration and testing of different disaggregated elements, but the benefits that come with Open RAN outweigh these complexities. These benefits are very tangible and are numerous. The following bullet points describe some of the key benefits of Open RAN [1],[5].

A. Network sharing

Allows multiple operators to have segregated networks and provide network services using the same RAN by using multiple VNFs sitting on the same platform.

B. Better Security

Open RAN provides operators with better visibility and control of network's end-to-end security built and based on 3GPP's advanced security for 5G NR.

C. Prevention of Vendor Lock-in

Current RAN products from legacy vendors, such as Nokia, Ericsson etc., are proprietary and closed, but with Open RAN, new open interfaces between RU and DU have been defined and specified. This openness helps with the supply chain diversity, solution flexibility and new capabilities. This helps lowering the barrier of entry for new suppliers and better vendor diversity.

D. Cost Reduction

Disaggregation of different RAN components and softwarization of some of them such as DU and CU helps reducing the deployment and maintenance cost. This also helps to virtualize and containerize different functionalities that could run on a single platform.

E. Energy Efficiency

Decomposition of network functions, such as DU and CU, and centralisation or Cloudification of these functions should improve the energy efficiency because of the ability to share these functions between many cell sites. According to [6],[7], up to 12% reduced power consumption of an Open RAN infrastructure using real-traffic scenarios during a PlugFest, Spring 2022, was achieved. However, further studies are needed to prove that Open RAN is more energy efficient than traditional RAN.

F. More Competion and Innovation

Open RAN has the potential to enable new entry and increase the level of competition and innovation in the mobile equipment market. Competition encourages innovation. Innovation on Open RAN, such as increased virtualization and optimization through cloudification, helps new entrants have the opportunity to win the market share.

V. TEST APPROACHES AND TEST CASES

Due to the limited scope and space of this paper, test approaches and test cases are described in a high level format as shown in the following subsections. However, the main focus and the scope of this paper is to describe the challenges and lessons learned, and to a lesser extent the details of the performed tests [6].

A. Test Aproaches

Given the complexity of Open RAN, test approaches were applied in phases. The main approach was to build a default chain or a reference combination with the easiest integration between the Open RAN components which would serve as a baseline case against which all the other combinations will be tested.

Once the integration of the components within a chain is completed and fully operational, it becomes a system under test (SUT) for interoperability testing and end-to-end system performance as shown in the figure below.

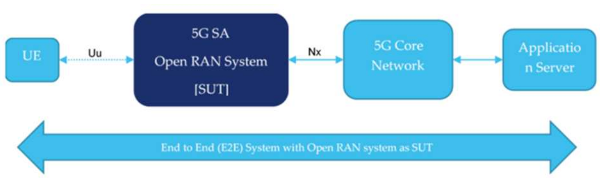

Fig. 2. System under Test for end-to-end test

Other tests performed were the peak DL and UL throughput followed by latency and mobility KPIs. The approaches for these tests were aligned with the relevant specifications from the main Open RAN standards organization O-RAN Alliance.

B. Test Cases

Some of the test cases considered during the initial phase of the Open RAN deployments are described below:

- Deployment test case
  - All the Open RAN components were deployed and tested individually including the PTP, precision time protocol.
- Connectivity test case
  - All the Open RAN components and sub-elements, such as CU-CP and CU-UP were connected with each other using the interfaces based on the Open RAN reference architecture described earlier in this paper
- Fronthaul test case
  - Tests between different planes, i.e. service plane (S-plane), management plane (M-plane) were performed
- End-to-end performance test case
  - System under test in this case is treated as a black box between UE and an application server as shown in figure 2
  - This test assessed the maximum traffic on DL and UL directions for a single stationary UE under excellent radio conditions
  - Reliability test included latency and maximum throughput in a periodic manner
- More test cases are planned for the next phases of the Open RAN deployments

VI. CHALLENGES OF OPEN RAN DEPLOYMENT

Most of the Open RAN testbeds are developed in phases, as this was the case with SONIC Labs and Vodafone Lab and probably others too, starting with the key functionalities, such testing the connectivity between different Open RAN components, and leaving the more complex ones, such as management and orchestration through RIC and performance testing, for next phases [8],[9].

Those involved in building these testbeds during the first phase try to rely on in-house resources and deployment skillset not knowing the full scale of the deployment complexity.

Some of the key challenges for those relying on in-house integration where it was obvious they did not have the full skillset for this integration were as following:

1. The integration on both levels, hardware and software was more challenging than anticipated
   a. This had some impact on the performances of the 5G SA Open RAN system, i.e. lower data rate than expected due to the lack of proper optimisation
2. It required more resources and it took longer than planned and anticipated
   a. This obviously led to a less cost efficient exercise and also had an impact on the deployment timeline

3. Reluctance of Open RAN vendors to try swapability tests
    a. Not all the vendor products were able to interact with other products, in particular the diversification between CU and DU remains still a challenge
    b. This led to a shorter number of functional tests performed than initially planned
4. Integration and deployment of a 5G SA Open RAN system at both, hardware and software level proved to be more challenging than anticipated
    a. Scale of manual configuration required was a contributing factor
5. Validation of Open RAN products in a wide range COTS platforms
    a. Open RAN suppliers need to grow the COTS supply base on which their products are based
6. Lack of time to complete the list of test cases due to the challenges during the deployment and integration phase
    a. Demand for RIC integration within the Open RAN deployment is still behind compared with the integration of other components and hence less efforts for this integration are made
    b. RIC will be considered during the next phases of Open RAN integration enhancements

VII. LESSONS LEARNED

Facing these challenges and learnings from these challenges [3], [6], and also having in mind the scale of future deployments, some of the lessons learned could be summarised as following:

A. New Skillset Is Needed

Integration of Open RAN requires new skill assets that a large proportion of engineers and experts from the industry don't have them yet.

This is very important in particular when operating in a 5G SA environment and will lead to the need for System Integrators or operators invest massively in their in-house skillset enhancements.

B. Increasing Complexity

Having additional factors added, such as MEC (Multi-access Edge Computing), Cloud, Slicing, RIC etc., makes the Open RAN integration even more complicated [10].

C. Performance of Thorough Tests

Some vendor products not necessarily would support open interfaces despite their claim they do, as seen during these deployments, and as such multiple detailed tests are needed prior to end-to-end integration and full deployment.

Every single Open RAN component and every individual end-to-end solution should be tested and validated carefully to ensure standard compliance and correct interpretation of specifications

Because of this rigorous testing requirement, System Integrators are better equipped and provide better expertise to avoid any potential delay and unexpected complications

D. Configuration Automation Process

The scale of manual configuration in a 5G SA system deployment was very challenging and time consuming. Hence, the need for an automated testing platform is the way forward and a roadmap for many testbed and testing platform providers.

E. Need for an SLA on System Level

Working in a multi-vendor environment adds to the complexity and validating functions on individual Open RAN components does not guarantee success. Individual vendors can be held accountable for their own specific products and to specific SLAs, but this again will not ensure the operation on an end-to-end level and as such an assurance SLA on the system level and single point of responsibility is needed [10],[11].

F. Post-deployment Open RAN Management

Completion of the Open RAN solution deployment is not the end of the story. Management of a deployed Open RAN is a constant challenge since it requires updates, upgrades and troubleshooting all the time and the integration with the rest of the infrastructure, such as 5G Core and other system elements including servers, switches, firewalls etc. The experience from the already Open RAN deployments has proven this to be very challenging and time consuming.

To mitigate these challenges some automation and streamlining of processes is required. This can be achieved through some agile development methodologies, such as CI/CD (Continuous Integration/Continuous Deployment).

VIII. CONCLUSIONS

Though the Open RAN products and solutions are more mature and improving all the time, the integration of these multi-vendor Open RAN products is still challenging and require additional in-house skills or system integrators specialized in Open RAN. The complexity will increase further with the addition of other features, such as MEC, RIC, slicing etc.

The focus of the initial stages of the deployment was on interoperability testing and end-to-end benchmark testing. For each chain, there were at least two different vendors for each Open RAN component which met the key requirement of a full vendor diversity.

Even though RIC capabilities were not tested fully during the initial phase in different Open RAN Testbeds, it is not hard to prove that RIC is the key that provides a unique opportunity for Open RAN and is seen as the main driver of Open RAN adoption by the operators and service providers and as such will be further tested in the next phases.

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