5G InterOPERAbility of Open RAN Components in Large Testbed Ecosystem: Towards 6G Flexibility

Thomas Höschele*, Florian Kaltenberger† Andreas Ingo Grohmann*, Elif Tasdemir*,
Martin Reisslein‡, Frank H.P. Fitzek*§
*Deutsche Telekom Chair of Communication Networks, Technische Universität Dresden, Germany
†EURECOM Institute, Campus SophiaTech, 450 Route des Chappes, 06410, France
‡School of Electrical, Computer and Energy Eng., Arizona State University, USA
§Centre for Tactile Internet with Human-in-the-Loop (CeTI)
Email: {firstname.lastname}@tu-dresden.de; Florian.Kaltenberger@eurecom.fr; reisslein@asu.edu

***Abstract*—An Open Radio Access Network (Open RAN) is a mobile network architecture that allows a Mobile Network Operator (MNO) to use network components from different vendors thanks to open interfaces between components and virtualization of parts of the mobile network which are currently provided by specialized software and hardware. The Open RAN concept enables the flexible customization of mobile network architectures according to specific use cases or required Key Performance Indicators (KPIs). As the diversity of architecture component vendors further increases and innovations further accelerate with 6G, the interoperability of network elements needs to be guaranteed so as to ensure flexible 6G system configurations. This paper describes the interoperability aspects in Open RAN and gives an overview of the available 5G Open RAN testbed ecosystem which is provided by the French-German collaboration project 5G-OPERA. More specifically, three major testbeds are introduced in this paper: 1) The OpenAirInterface (OAI) testbed is an open-source project developing RAN, Core Network (CN), and RAN Intelligent Controller (RIC). 2) The 5G-Core testbed including traditional vendors and Open RAN solutions, currently complemented with open-source CNs. 3) The industrial testbed, which is the largest available Open RAN testbed for private networks in Germany. These testbeds enable the benchmarking of traditional and new vendors and thus provide an environment for examining the interoperability of network components from different vendors as well as particular component features. Moreover, Open RAN boosts innovations, such as network slicing and localization, which can be tested on the 5G-OPERA experimental platform. The insights provided in this paper into 5G testbeds can contribute to the foundations for building experimental platforms for examining the interoperability of future 6G system components.**

***Index Terms*—5G-OPERA, 6G Experimental platform, Interoperability, Open RAN, Testbed.**

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I. Motivation

With the 5th generation of the mobile communication standard (5G) being largely rolled out and the 3rd Generation Partnership Project (3GPP) Release 17 being on its way, the research community starts to focus their efforts on the 6th generation of the mobile communication standard (6G). The main questions being discussed are the vision of 6G, what changes and advances the technology should include, as well as which new use cases will be enabled by 6G, driving digitization of our everyday lives. While 5G has been placed as a revolution in contrast to 4th generation of the mobile communication standard (4G), the question arises if 6G will be an improved 5G or whether completely new concepts will broaden the vision for 6G. New concepts could include quantum networks [1] and Post-Shannon algorithms [2], being currently discussed and gaining research interest. However, the current technology stack, which is widely used for 5G networks, will also evolve as novel concepts, such as softwarization, virtualisation, and Radio Access Network (RAN) disaggregation emerge [3]. It is likely that these emerging concepts will influence the development of 6G. Therefore, in order to lay a foundation for effective 6G experimental testbeds, it is critical to thoroughly understand 5G testbeds that encompass these emerging concepts.

Three concepts, softwarization, virtualization and disaggregation or RAN, have been driving development in 5G. Softwarization describes the abstraction of functions from specialised Application-Specific Integrated Circuits (ASICs) to source code implementations, that can be executed on a general-purpose CPU or GPU [4]–[7]. Essentially, softwarization moves the realisation of communication networks from a hardware-focused industry towards software. Virtualization of systems pushes this concept further, by abstracting the Operating System (OS) layer underneath, separating the OS from the software itself; thus, enabling the source code being flexibly deployed, executed, as well as scaled and moved in containers on any Commercial off-the-shelf (CotS) hardware [8]–[11]. Disaggregation of the RAN, separates the various aspects of the network into separate functionalities, making it possible to utilize the first two concepts by running specialised software and interfaces on virtual machines to implement processing algorithms of the RAN. Resulting in passive Radio Unit (RU) being left as the only specialised hardware component of a possible commercial telecommunication network.

These three concepts have been combined in the concept of Open RAN [12]–[14], which specifies that open standardised interfaces between different components have to be used, with the main focus being cost reduction while increasing flexibility. In order to be fully functional on a large scale, these concepts will require a platform to provide experimental results for the challenges of the current technology stack on the road towards 6G. The experimental platform should validate the implementations of the concepts, retrieve measurements for comparison between traditional and Open RAN systems, and improve the 5G technology stack along the way. This is true for deployments of the technology in public telecommunication networks by the Mobile Network Operator (MNO) we use in our everyday lives, additionally for the emerging field of private 5G networks [15]–[17] which utilize the capabilities of wireless communication technology for automation of process and digitization of vertical industries [18]–[21].

The remainder of this paper is structured as follows. In Section II, the advantages of Open RAN and the general architecture is described, an argument for the requirement of interoperability is made in order to achieve the advantages. In Section III, we describe a selection of testbeds from the experimental platform and their main aim. In Section IV, specific innovation areas of Open RAN are discussed while Section V provides the conclusion and outlook.

II. Platform for Interoperability

Particularly the disaggregation concept, which builds on softwarization and virtualization, enables new technology vendors to enter the current market place of traditional telecommunication equipment providers; thus, increasing the overall ecosystem. Those new vendors do not specifically build complete 5G systems, but can focus on a particular component of the disaggregated architecture and then cooperate with partners that develop the other components. The currently largest specification and implementation of such a disaggregated open RAN technology architecture is provided by the O-RAN alliance. The O-RAN architecture specification breaks the traditional components of a RAN into a few smaller components, with openly defined interfaces between them. The most important elements are the RU, the Distributed Unit (DU), and the Centralized Unit (CU), which make up the main elements of a traditional base station. Their names come from the way they are deployed. A centralized unit can serve multiple distributed units in a region and typically is deployed in a local data center or in a central office. The data link between the CU and DU is called midhaul. The DU can serve multiple RUs and can be deployed in a street cabinet, in a building, or on a floor of a multi-story building. The data link between the DU and RU is called fronthaul. Each of the radio units must be collocated with an antenna, which serves a specific geographic area. Together with the Core Network (CN) and the User Equipment (UE) the mobile communication network is complete. Figure 1 visualises these components and their connections. The link between CN and CU is referred to as backhaul. In an open RAN design, interfaces between the different elements as well as real-time control and management and operation are openly defined by standardization bodies, such as the O-RAN Alliance (www.o-ran.org) or the 3GPP (www.3gpp.org). As technology providers can focus on the development of just one component, the following major advantages are possible with the Open RAN concept:

1) Traditional telecommunication hardware has been expensive in Capital Expenditure (CAPEX), the availability of Open RAN being executed on CotS hardware gives the provider of the infrastructure the opportunity to buy hardware at much lower cost. Also, the increased competition of more vendors offering solutions can decrease the overall cost for hardware and software.
2) Open RAN is supposed to drive innovation as new technologies and algorithms could be deployed through software-updates in near real time. With an increased number of innovative companies, different features and functionalities for specific industrial requirements can become available in the market. This should boost the possible application scenarios for mobile communications.
3) With the virtualisation of the processing algorithms, existing and new server hardware can be better utilized. This may make it possible to deploy such Open RAN networks on the existing IT infrastructures of factories, business parks, or hospitals, which is another important cost-reducing factor.

The big promise is to have a possibility to flexibly choose and customize a solution from various different vendors to find the perfect match to a specific use case or Key Performance Indicator (KPI) particularly required by the customer. Unfortunately, in reality this turns out to be one of the biggest challenges. The increased diversity of the possible vendor ecosystems and more rapidly introduced technological innovations pose a major challenge: The interoperability of the components must be ensured. While a lot of different O-RAN vendors and open-source solutions struggle to have all three components running in a stable and reproducible manner out of the box from only one vendor, the interoperability of components from different vendors is an enormous challenge. This interoperability challenge will need to be tackled to fulfil the promise of customization, especially for private networks, as their requirements will be more diverse in nature. To meet the challenge for future public networks, as well as private networks we established a test platform. While the platform is built with software and hardware for private networks, the results of the platform can easily be transferred to the operation of public networks since private vs. public networks mostly differ in the number of connected users.

To test and verify this interoperability we introduce the

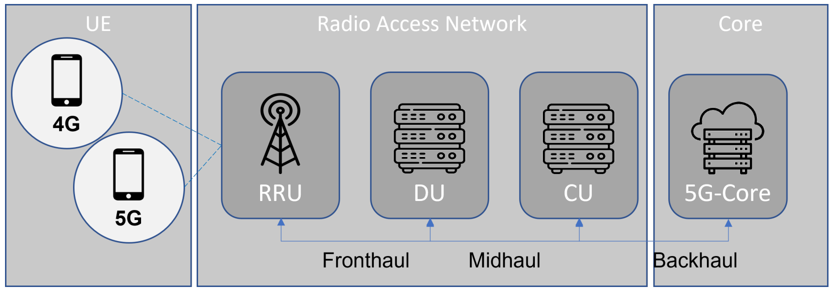

Fig. 1. Open RAN Split: Dedicated components

experimental platform provided by the French-German collaboration project 5G-OPERA. The 5G OPERA platform stretches between France and Germany and encompasses multiple test sites in each country.

III. Testbed Ecosystem in 5G-Opera

A. Overview

The partners of the 5G-Opera project include technology vendors, universities, and research institutions that are at the forefront of the 5G development, with each partner providing individual expertise in one or multiple areas. The overall goal of the 5G-Opera project is to ensure that the hardware and software components of all partners can smoothly and flexibly interact and integrate with each other, regardless of vendor variety. To achieve this overall goal, smaller steps will be required. These steps will build a basis for an interoperability experimental platform beyond the project consortium. The platform could then support operators and vendors, identifying and isolating the problems with their preferred technology combination. The platform will need to integrate the different components by each vendor and to develop standardised test and measurement procedures for comparison. To achieve these results, some project partners offer different facilities to run the interoperability testing.

B. Major 5G-OPERA Testbed Facilities

This section describes three major testbed sites in the 5G-Opera project, which can serve as examples for other testbeds and possible experimental platform solutions.

1) Eurecom OAI Testbed: One of the available testbeds in 5G-Opera is based on the open-source project for mobile communication technology, OpenAirInterface (OAI), which was initiated by Eurecom, Sophia Antipolis, France. Besides being a research center in the areas of digital security, data science, and communication system, Eurecom is also a French graduate school. After being initiated by Eurecom, OAI became a cooperative project with many academic and industrial partners [22]. The open-source project is managed by OAI Software Alliance (OSA). The aim of OSA is to develop RAN and CN based on the 3GPP specifications. The open-source software can run on (x86) CotS platforms together with Software Defined Radio (SDR) cards [23]. OAI is the most complete open-source implementation of 5G networks today and can run a complete network on general purpose computing and radio infrastructures.

Although OAI is a good starting point to run a complete network, there is still some work to be done to make OAI compatible with O-RAN specifications and to improve its stability to make it ready for real deployments. Moreover, OSA has launched a project called MOSAIC5G which develops a Flexible RAN intelligent Controller (FlexRIC) to monitor and control the RAN in real time. The FlexRIC contains similar functionality of Near-Real Time (Near-RT) RAN Intelligent Controller (RIC) of the O-RAN Alliance. However, FlexRIC is smaller, easy to deploy, and well suited for experiments. Eurocom will mostly focus on the integration and test of different RAN components and their interoperability. With OAI they can change the complementary components rather easy to identify problems and find solutions to make interoperability possible.

2) TU Dresden 5G Core Testbed: The Technical University Dresden (TU Dresden), which is one of the ten universities of excellence in Germany, brings testbeds with equipment from different vendors to the testbed ecosystem. Those testbeds can be used for interoperability tests in the 5G-Opera project. One setup is based on the OAI softwares on two general-purpose computers with Xeon microprocessors and two N310 series Universal Software Defined Peripheral (USRP) devices. Another setup is from Airspan, which is a American telecommunications company developing RAN. The network consist of various standard components made by Airspan. Specifically, two AirVelocity 2700 Indoor RUs, combined with a virtualized CU (vCU) and a virtualized DU (vDU) running on two CotS servers, form a 5G RAN. All interfaces between those dedicated components are open and described according to the O-RAN Alliance specifications. The interfaces between vDU and vCU are described according to the 3GPP specifications [24]. This setup is completed with the integration of an open-source core network being either 5GS or OAI. TU Dresden can also provide traditional mobile communication networks from Nokia, Huawei, and Ericsson. Except for Ericsson, the equipment is integrated with an open-source 5G-Core. The Ericsson system is closed to 3rd party components. For the experimental platform it is important to benchmark the KPI of the Open RAN solutions against traditional equipment. In 5G-

Opera, TU Dresden focuses on the interoperability of different RAN systems with different 5G-Core implementations, and thus supports benchmarking between traditional vendors and new vendors.

3) Fraunhofer IIS Industrial Testbed: Fraunhofer Institut für Integrierte Schaltungen (Frauenhofer IIS) is headquartered in Germany and conducts information systems research across a wide range of research institutes [25]. Frauenhofer IIS is part of the OSA technical committee and contributor of the 3GPP standardization body. Frauenhofer IIS has installed a 5G Open-RAN Testbed for Industry 4.0. which is suitable for interoperability testing. The testbed is placed in two sites, on in the city of Erlangen, one in the city of Nuremberg, with a central CN hosted in Nuremberg. [26]. The testbed equipment components are commercial 5G Stand Alone (SA) RAN components together with emulation facilities. In total two CUs, five DUs and over 80 RUs are installed, making it the largest Open-RAN testbed in Germany. With this testbed, customer-specific use cases in industry and logistic can be tested. Being deployed on two sites across multiple different areas, interoperability tests can be performed. However, he Frauenhofer IIS testbed also aims to focus on implementing new technological innovations and on providing interoperability solutions for them.

IV. Functionalities Enabled by Open RAN

Besides enabling services providers and operators alike to use non-proprietary components from different vendors, Open RAN also enables the rapid implementation of innovations [27]–[37]. Those innovations cover a range of topics, some introduced in the RAN, while others have to be included in the CN. This brings an additional level of complexity to the challenge of interoperable solution from different vendors, as some components may simply not support certain features.

An open RAN innovation that providers can use, is the RIC to control and optimize the RAN in an intelligent, agile, and programmable way. For example, the RIC can optimize the quality of experience for different user groups with different requirements, such as video streaming or gaming. The RIC can also optimize the coverage and network throughput by traffic steering or coverage optimization. The Open RAN will be composed of both Near-RT and Non-Real Time (Non-RT) RICs as described in the O-RAN Alliance architecture specification. Non-RT RIC will manage learning based on the ML/AL models within the Service Management and Orchestration (SMO) platform. Non-RT RIC is expected to act on a time scale more then one second. On the other hand, Near-RT RIC is a node that controls and optimizes elements and resources of RAN within 10 milliseconds and 1 second. Near-RT RIC will host applications such as scheduling, RAN slicing policies, and load balancing, whereby Non-RT RIC will host third party applications [38]. Non-RT and Near-RT RICs communicate over the A1 interface, while Near-RT RIC communicates with CU and DU over the E2 interface. Mobile network operators can reap the full benefits of the Open RAN architecture with RIC.

Another innovation that can be implemented in the Open RAN components is network slicing. Network slicing is an architecture in which a physical network is divided into separate virtual networks to create specific paths with different Quality of Service (QoS) for each traffic stream over a single RAN. Network slicing will play a critical role because different use cases needed to be supported. The open interfaces and RIC are the technologies that will help to tune the RAN behaviors and to provision RAN slices. It will also be possible to slice networks with functions provided by different vendors. For instance, one slice which is supposed to provide massive Machine Type Communication (mMTC) can be built of the DU and CU from vendor A, while another slice which supports Ultra Reliable Low Latency Communication (URLLC) can be built of the CU and DU provided by vendor B [39].

Additionally, various localisation algorithms that are proposed by 3GPP can be verified within the Open RAN testbeds. Localization and positioning are essential parts of the public and private network applications and will be utilized in vertical industries, such as smart factories, autonomous vehicles, and logistics. Either Down Link (DL) or Up Link (UL) based positioning algorithms can be used based on Time Difference of Arrival (TDoA). TDoA is a method measuring the time difference of the reference signals received by UE in DL or at the RAN in UL. This accurate timing is used to estimate location of the UE. DL Positioning Reference Signals (PRS) for DL can be used as specified in 3GPP Release 16, Sounding Reference Signal (SRS) can be used for UL as specified in 3GPP Release 15. A new network entity, i.e., Location Management Function, has been introduced in CN to determine the location of the UE.

Last but not least, some important use cases for Industry 4.0 private scenarios require Time Sensitive Networking (TSN) capabilities. TSN is a series of standards for wired Ethernet communication defined by Institute of Electrical and Electronics Engineers (IEEE) 802.1, working on Layer 2 [40], [41], and guarantees timely delivery and minimizes jitters on standard Ethernet through specific TSN scheduling mechanisms [42], [43] that cooperate with 5G [44]. The 3GPP has specified a first architecture for the integration of TSN and 5G network in Release 16&17. One task will be to port and test this with an open RAN network.

V. Conclusion and Outlook

The experimental platform of 5G-Opera will be an important pillar to foster the development from 5G to 6G in the area of Open RAN. The 5G-Opera platform provide an ecosystem for examining the interoperability of different vendors, components, and specific features.

The exchange of knowledge for the best ways to test and integrate different components and features among research and development teams will improve the quality of the individual components and reduce the development time. The development of standardised and proven measurement test-suites will facilitate the comparisons between the different solutions; thus, helping operators and costumers alike in their decision making

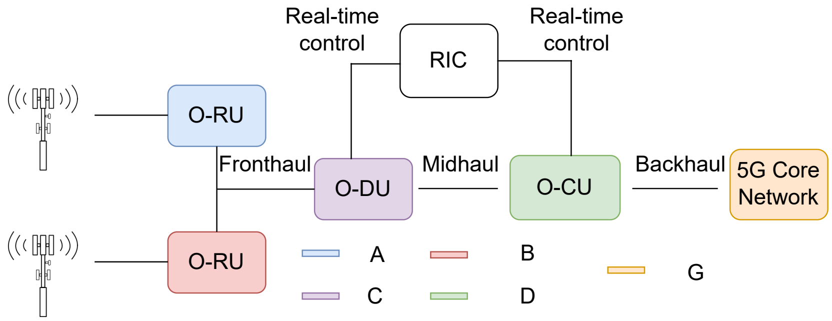

Fig. 2. Illustration of the multi-vendor components in Open RAN from different vendors, i.e., vendors A, B, C, D, and G.

processes. The ability to instantly identify errors to be resolved in improvements will benefit the partners of the 5G-OPERA project as well as organizations outside the project. Building an ecosystem of providers outside the project, particularly for a sovereign digital European ecosystem, led by France and Germany, will contribute to improving the overall quality of the solutions on the market. Being able to test the features as well as providing open-source software stacks for the ecosystem will enable customized networks for special use cases. At the same time, the Open RAN systems should aim to achieve comparable overall performance levels as traditional systems. This will also result in best practices and knowledge on integration, testing, measuring, and validating the functionalities provided by the solutions among the partners. 5G-Opera will present these results in future publications and will also communicate them to the standardization bodies. In the end, one of the major promises of Open RAN, namely a CAPEX reduction for a system, and possibly an overall cost reduction, may be achieved due to this customization and comparison of different interoperable solutions. Such cost reductions and flexible customizations would enable users to introduce 5G-networks that fit their specific needs and are economically reasonable, while informing future 6G developments.

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