The 5G-OPERA Approach: A Roadmap towards an European OPEn RAn Ecosystem for 6G

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***Abstract*—Although the digital sovereignty of Europe has become increasingly important in recent years, one blank spot remains: mobile communication infrastructure. Increasingly frequent global crises like pandemics and wars are leading to less reliable supply chains especially of high-tech equipment and products, requiring an European strategy to gain the technological lead. Towards this end, the joint French-German project 5G-OPERA started in 2022 with the mission to establish a binational and ultimately European ecosystem for Open Radio Access Network (RAN) solutions. This ecosystem for private, Open RAN 5G networks will accelerate the digital transformation in Europe to Industry 4.0, and increase the resilience of critical communication system throughout the society. At this time, 5G-OPERA directly resulted in more than 30 scientific publications, an European patent in the domain of mobile networks, and multiple commercialized developments. Moreover, various trade fair participations, workshops presentations, and networking events extended the ecosystem already beyond the initial project scope. In this work, we outline the general approach of 5G-OPERA, the direct results of the project, and present an outlook how this ecosystem building will work as a blueprint for future 6G research.**

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

I. Introduction

The realization that the digital sovereignty of Europe is becoming ever more important, resulted in the cooperation of France and Germany to foster a mobile communication ecosystem for industrial applications. Under the joint leadership of two leading research institutes in that area, *TU Dresden* and *Eurecom*, the project 5G-OPERA concentrated the expertise of more than ten partners, both from academia and research. The focus of the project was the idea of open hardware, software, and interfaces allowing the combination of different equipment providers to flexibly realize 5G Non-Public Network (NPN). Especially, the interoperability between the components of all the different project partners was an overall goal of 5G-OPERA, enabling distributed in-depth research at multiple major testbed sites [1]. In addition to the implemented reference test environments, focusing on use-cases for the digital transformation of Industry 4.0, 5G-OPERA was accompanied by multiple satellite projects [2]. Those supplementary projects each focus on a particular set of coherent industry specific use-cases, further stimulating the developed Franco-German ecosystem for private 5G networks.

The project 5G-OPERA started back in 2022 with the vision to have a noticeable impact of the European market for industrial mobile communication solutions. This included four major elements to fulfill the goals. First, on a technical level, creating the fundament of a combined Franco-German ecosystem commercializing cutting-edge mobile communication technology based on virtualized Open Radio Access Network (RAN) concepts. This aspect extends into fostering a partner network for providing interoperable, high-performance Open RAN equipment with a high degree of possible customization for various network providers and verticals. Additionally, this ecosystem will identify potential customers and prospective cooperation partners, by ultimately involving suppliers, vendors, and research bodies. Second, in a political domain, promoting digital sovereignty of initially France and Germany, but ultimately as a role model for the European Union. This binational cooperation presents a possible blueprint for a broader European strategy to gain the technological lead, as well as to strengthen the labour market in the region. Third, organizing the coordination of the mutual transfer of concepts, architectures and solutions for 5G NPNs between various french and german institutions and companies. Fourth, incorporating network operator models and other country specific regulatory aspects of France, Germany, and other European countries to develop open NPN operation solutions.

The mission of the project was closely tied to industry forecasts and trends in the respective market. The Open RAN market is predicted to outgrow the traditional RAN market by 2030, offering the opportunity to redistribute market shares from the international big players to European companies. Moreover, Open RAN solutions are expected to significantly reduce the Capital Expenditure (CAPEX) and Operational Expenditures (OPEX) of private 5G networks [3]. In combination with the developed and improved network infrastructure itself, various innovations will enable application opportunities for vertical industries. The project should enable partners to offer novel and competitive products in this growing Open RAN market, that are reliably tried and tested in the 5G-OPERA testbed ecosystem. Collectively, 5G-OPERA aimed to substantially increase and reinforce the digital sovereignty. Project reports and various results are publicly available [4]. In the following, Section II describes 5G-OPERA as a project platform

on an organizational and technical level, Section III shows the technical contributions of the project, and Section IV provides an outlook towards the requirements for future 6G research based on the lessons learned in 5G-OPERA.

II. 5G-OPERA Platform Overview

The envisioned ecosystem will span across all components of a full-fledged Open RAN system. Fig. 1 shows that the project partners of 5G-OPERA cover every aspect of traditional 5G mobile networks and the additional Open RAN components. Hence, this consortium is capable of building the foundation for the intended European ecosystem. Each project partner contribute their own in-depth knowledge of a certain part of the overall system to advance the developments of the entire ecosystem. Moreover, Fig. 1 shows the connection between the Open RAN components themselves and the innovations build on top of this infrastructure. The integration of developed software and hardware solutions into a operational complete 5G system has the advantage to give each 5G-OPERA partner a much higher exploitation potential than a component-wise exploitation and dissemination on an individual level. Another aspect is the high reuse potential of developed components in future projects or licensing to third parties. Therefore, 5G-OPERA enables the industry partners to enter the respective market subsequently stabilizing the market itself as a symbiotic effect. Specifically research facilities increase their knowledge base in all technical and organizational aspects of the ecosystem, spanning from Open RAN and Core Network (CN) architecture, over private networks and integration in general, to suitable operator models. Both, academia and industry, benefit from the educated personnel in the area of the project, resulting in more and better educated employees in the industry.

However, to fully unfold the potential of the 5G-OPERA platform, one aspect is central: open source software. At the heart of project is the OpenAirInterface (OAI), an open source 5G implementation initiated and managed by the project member *Eurecom*. Open RAN in general and specifically open source software of the components is crucial to enable research [5]. This includes fundamental research such as development of Integrated Access and Backhaul (IAB) with hardware acceleration [6], new frequency bands in the terahertz range [7], novel coding approaches [8], or the research on closed source Commercial of-the-Shelf (CotS) components [9]. Non of those Proof of Concept (PoC) experimental implementations is possible with regular closed source mobile communication equipment and components. Additionally, it is worth noting that the performance of open source software is comparable with traditional systems [10]. Moreover, open source is also essential enabler for the industry. Several industrial project partners used open-source software developed in 5G-OPERA directly in their products as we will see in the following Section III. Last but not least, open source also enables the development of patentable innovations [11]. These results already show that it is not only possible to develop innovations and commercial products on the basis of open source, but that open source makes this goal possible in the first place.

III. Open RAN Components and Innovations

There are two types of major technical results 5G-OPERA produced. The first category are advancements in Open RAN and 5G platforms in general via novel developments spanning across hardware, and software platforms as well as system integration. The second category includes innovative solutions and experimental implementations on the top of open RAN compliant private 5G networks.

A. Open RAN Components in Virtualized Non-Public Networks

The OAI is a fundamental component of the 5G-OPERA project, as it is used in all testbeds and crucial for the development of PoC implementations. Hence various project partners focused on improving the OAI itself. Before 5G-OPERA the OAI was mainly addressed at the scientific community [12], offering an already complete implementation of the 3rd Generation Partnership Project (3GPP) 5G RAN stack with a partially limited interoperability with commercial User Equipments (UEs). However, there was no support for integral Open RAN aspects like Centralized Unit (CU)/Distributed Unit (DU) split operation, an 7.2x fronthaul support for O-Radio Units (RUs), or control interfaces (E2 and O1). Summarized, the option for commercial use was quite limited. Towards this end, *Eurecom* substantially extended the OAI software project [13] throughout the duration of 5G-OPERA. The major developments include support for disaggregation (F1 and E1 interfaces), and O-RAN 7.2x fronthaul support, the possibility of a broad range of hardware acceleration [14], [15], and the integration of management and control capabilities (E1 and O1 interfaces). In close collaboration with *Eurecom*, the company *Firecell* designed and commercialized their Orion O-RAN labkit. It is an easy-to-deploy and user friendly solution for experimental 5G NPNs, enabling the rapid development and subsequent testing of experimentally customized Open RAN based solutions. *Fraunhofer HHI* also contributed directly to the optimization of the OAI, e.g. integrating multiple Quality of Service (QoS) classes and enhancing the interoperability of the software with different O-RUs. Morevoer, they integrated near real-time and non real-time RAN controllers to build extended end-to-end setups for evaluating novel system features and control loops.

In addition to the RAN software itself, multiple project partners worked on integrating hardware acceleration cards. As a result, 5G-OPERA expanded the available hardware acceleration options for Open RAN from international industry leaders (such as Intel, AMD and Nvidia) to include European solutions. *Kalray* developed a hardware acceleration card for DUs building on its own MPPA Coolidge v2 processor, featuring high-speed interfaces and 5G-specific acceleration chips. Open RAN systems using the developed PCIe-based Kalray K300 acceleration card showed significant performance

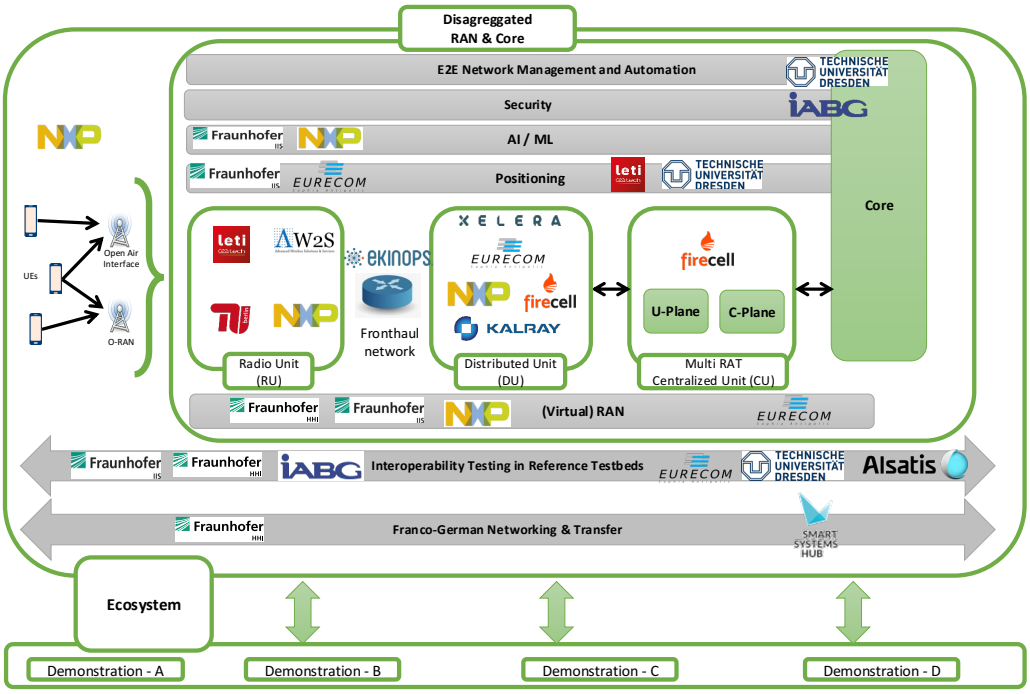

Fig. 1. The different project partners of 5G-OPERA cover the entire 5G and Open RAN stack, enabling the creation of a joint ecosystem. This includes the technical aspects as well as the creation of the ecosystem itself, including the interplay with satellite projects at the bottom and the Franco-German networking and knowledge trasnfer.

improvements compared to similar systems without acceleration. The two project partners *Xelera Technologies* and *NXP Germany* worked in close collaboration to integrate the entire 5G CU and DU stack on a NXP-based accelerator card. This approach yields to a lower energy consumption, lower total hardware costs, and higher overall performance. The system is a complete O-RAN compliant solution capable of addressing multiple O-RUs and hundreds of UEs per unit. As a direct result of 5G-OPERA, this solution is available in Europe under the name of Xelera DYRA (DYnamic RAn) as a commercial solution.

Moreover, *NXP Germany* adapted their Glasgow board to build a 2T2R RU with integrated ehanced Common Public Radio Interface (eCPRI) support. This O-RU hardware platform showed the seamless integration of open source 5G software stacks with ARM-based platforms. *TU Berlin* developed a radio head for a mmwave RU, consisting of a 4x32 cylindrical antenna array including lower PHY processing and beamforming capabilities. This design is O-RAN 7.2x fronthaul compliant and will be interopable with other O-RAN components. *AW2S* is developing 5G NEO, an RU that is operable with CPRI split 8, as well as O-RAN 7.2x fronthaul. The 5G NEO is already commercially available, but due to various technical challenges in the development only CPRI split 8 compatible at the moment. However, the integration of the O-RAN 7.2x fronthaul continues after the end of the 5G-OPERA project, and will become available in 2026. Dealing with the fronthaul network itself, *Ekinops* developed an adapted Layer 2 switch supporting the necessary timing and synchronization features. This includes boundary clock support (based on IEEE1588v2 PTP/SyncE), ultimately enabling the transport of eCPRI fronthaul traffic over an Ethernet network between multiple O-RAN nodes (from one O-DU to multiple O-RU). *CEA-Leti* worked on IAB with mmwave, with a hardware based PoC implementation including Reconfigurable Intelligent Surfaces (RIS) [16].

B. Innovations in Open RAN and Core Networks

Complementary to the developments and improvements of the Open RAN system itself, 5G-OPERA also created multiple innovative features adding novel capabilities to the overall network. This includes the development of AI-driven xApps for network optimization, the evaluation and integration of Time-Sensitive Networking (TSN) aspects, the support of live positioning of UEs, an in-depth security analysis, and network management features and concepts. In the following we present a brief summary of the contributions by 5G-OPERA for each topic.

The O-RAN specifications introduce multiple RAN Intelligent Controllers (RICs) to enable network monitoring and control. Moreover, this enables the utilization of machine learning models to optimize the mobile network. Multiple xApps, using the near real-time RIC, have been developed. This includes theoretical basics for the use of deep reinforcement learning [17], the conception and implementation of load balancing across the RAN [18], and the investigation of conflict management between multiple concurrent running xApps [19].

The main focus of TSN is the realization of deterministic and reliable network services with low latency. Those technologies exist in the wired domain and their integration into 5G is important to allow for industrial use-cases [20]. In the 5G-OPERA project, this includes on a fundamental level the development of features in the OAI code base. Additionally, the resource allocation in the RAN to allow the coexistence of regular traffic and prioritized TSN traffic was analyzed [21]. To integrate actual TSN components and therefore capabilities in 5G networks, network- and device-side translators were implemented on an experimental level. Finally the integration of TSN features in a live 5G system was shown and evaluated [22].

The tight collaboration between *Eurecom, Firecell, TU Dresden,* and *Fraunhofer IIS* in 5G-OPERA, resulted in the complete implementation of positioning services in the OAI [23], [24]. This includes the entire end-to-end system, consisting of CotS UEs, an OAI-based RAN and CN. This collaborative effort resulted in four significant advancements in the ecosystem: (i) The positioning functionality is completely integrated and tested in the OAI pipeline, resulting in a ready and reliably working solution. (ii) The implementation of the entire NR Positioning Protocol A (NRPPa) stack in both the RAN and CN. (iii) A working Location Management Function (LMF) has been written from scratch and is working properly with the OAI CN and the entire 5G system. (iv) Basic positioning algorithms based on uplink timing measurements are implemented and publicly available [25].

The collaborative efforts of *IABG*, *NXP Germany*, and *TU Dresden* resulted in the "5G OPERA Security Specific Extension" [4], a thorough and multifaceted analysis of Open RAN based networks. This work highlights the importance of robust security models, deploying private 5G networks, to ensure their integrity and reliability. Additionally, various recommendations and best practices are combined as the *OPERA Security Model* including for example traffic management, and encryption guidelines. On a higher level, 5G-OPERA shows the importance of collaboration between multiple domain-level experts throughout the entire ecosystem to advance the security level of the overall system. This includes active vulnerability assessment [26], as well as adopting continuously evolving security measures.

IV. Outlook towards 6G

In today's digital world, communication technology is a crucial part of our lives. From social media communication to data transfer between devices and servers, everything relies on a stable and secure communication infrastructure. To shape the future of communication technology, it's essential to develop and implement innovative solutions based on open-source principles. This is not only important for the development of new technologies like 6G but also for the integration of RAN and CN in 5G and 6G technologies [27], [28]. The integration of RAN and CN in 6G technology is a complex problem that requires experts from various fields to solve. RAN specialists are responsible for developing radio access networks, while CN specialists focus on developing core networks. To implement the integration of RAN and CN in 6G technology, we need experts from both fields to work together and share their experiences and knowledge. An example of an organization that specializes in developing RAN solutions is *Eurecom*. *Eurecom* is a research institution that focuses on developing communication technology and attracts experts from around the world. By collaborating with *Eurecom* and other organizations like *TU Dresden*. The development of communication technology is a global problem that requires experts from around the world to solve. However, to shape the future of communication technology, it's essential to collaborate on a European level. EU cooperation is a important step towards collaborative development of communication technology. Through EU cooperation, we can ensure that developed solutions are up-to-date and tested and improved by the community. EU cooperation also enables us to bring together experts from various fields and share their experiences and knowledge. This is particularly important in communication technology, where security and reliability are of utmost importance. An example of an EU cooperation that could shape the future of communication technology is the 6G-EU project. 6G-EU is a European project that focuses on developing 6G solutions and attracts experts from around Europe. By collaborating with 6G-EU and other organizations like *Eurecom* and *TU Dresden*, we can ensure that developed solutions are up-to-date and tested and improved by the community.

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