Autonomous Control and Positioning of a Mobile Radio Access Node Employing the O-RAN Architecture

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***Abstract*—Over the years, mobile networks were deployed using monolithic hardware based on proprietary solutions. Recently, the concept of open Radio Access Networks (RANs), including the standards and specifications from O-RAN Alliance, has emerged. It aims at enabling open, interoperable networks based on independent virtualized components connected through open interfaces. This paves the way to collect metrics and to control the RAN components by means of software applications such as the O-RAN-specified xApps.**

We propose a private standalone network leveraged by a mobile RAN employing the O-RAN architecture. The mobile RAN consists of a radio node (gNB) carried by a Mobile Robotic Platform autonomously positioned to provide on-demand wireless connectivity. The proposed solution employs a novel Mobility Management xApp to collect and process metrics from the RAN, while using an original algorithm to define the placement of the mobile RAN. This allows for the improvement of the connectivity offered to the User Equipments.

***Index Terms*—6G, Mobile Radio Access Network, O-RAN, xApp.**

I. Introduction

Mobile networks are constantly evolving in order to improve wireless communications and meet the ever-increasing Quality of Service (QoS) requirements. Throughout the multiple generations of mobile networks, new technologies have been introduced to meet those requirements, while the networks have become more complex, creating the need to properly configure, manage, and optimize their operation. This implies the exchange of data, analytics, and control actions between different components of the network.

The need to exchange and analyze high amounts of data and configure parameters across the network motivates the use of open interfaces between network components. However, the recently released commercial implementations employing the 5G New Radio (NR) technology typically rely on proprietary hardware and closed-source software solutions, especially for the Radio Access Network (RAN) part. This leads to multiple challenges, including vendor lock-in limitations, restricted configuration options, and limited inter-node coordination, which impose multiple challenges when it comes to deploying a reconfigurable 5G/6G network.

To address these limitations, the O-RAN Alliance [1] was founded, in 2018. O-RAN Alliance is a community that aims at leading the industry towards open, interoperable, and virtualized RAN components, by specifying a set of interfaces and standards. This paves the way for mobile network operators to deploy networks tailored to the performance requirements of targeted use cases, while minimizing the dependence on proprietary solutions. O-RAN enables the establishment of an environment that facilitates the collection of metrics from the RAN as well as the execution of control actions.

From the network performance point of view, mobile networks' goal is to meet the users' requirements, typically defined by means of targeted QoS levels. Achieving this in some scenarios may be challenging when using fixed RANs only, due to the obstruction of the line of sight between the User Equipment (UE) and the radio cells' antennas. The challenges are exacerbated when considering dynamic obstacles, which potentially lead to significant degradation of the QoS offered. Placing a gNodeB (gNB) on-board a Mobile Robotic Platform, which can be repositioned on-demand according to the dynamics of the environment, paves the way to provide enhanced wireless channel conditions and improved QoS to the UE.

The main contribution of this paper is a private standalone (SA) network leveraged on a mobile RAN employing the O-RAN architecture. The mobile RAN consists of a gNB carried by a Mobile Robotic Platform autonomously positioned to provide on-demand wireless connectivity. The proposed solution employs a novel Mobility Management xApp, which is able to collect and process metrics from the RAN, while using an original algorithm to define the placement of the mobile RAN in order to improve the connectivity offered to the UEs.

The remainder of this paper is structured as follows. In Section II, we present the related work. In Section III, we explain the proposed mobility management xApp. In Section IV, we detail the system design and implementation. In Section V, we describe the system validation, including the main results achieved. Finally, in Section VI, we refer to the main conclusions and future work.

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II. Related Work

There is a relatively low number of related works in the literature employing the O-RAN architecture. The works presented in [2], [4], and [5] use O-RAN based approaches to implement the network, including a Near-Real-Time RAN Intelligent Controller (Near-RT RIC) leveraged on the O-RAN Software Community (OSC) RIC, and an extended version of srsRAN [3]. srsRAN is an open-source 5G and 4G RAN software implementation, which allows users to deploy gNBs and eNBs.

FlexRIC [6] implements a Near-RT RIC that is less computationally demanding than OSC's and is able to connect to a eNB, implemented using srsRAN with an E2 Agent, while also simultaneously connect to a gNB implemented by means of the Open Air Interface (OAI) software package. OAI allows the deployment of 4G and 5G RANs, and Core networks.

ProSLICE [7] disaggregates the RAN itself by extending and enhancing the OAI RAN software package, while splitting the Central Unit (CU) provided by OAI into the CU-CP (Control Plane) and CU-UP (User Plane) components. ProSLICE also implements the E1 interface, supporting multiple Distributed Units (DUs), and an E2 Agent onto the E2 nodes (CU-CP, CU-UP, and DU). Moreover, the authors of ProSLICE have introduced several enhancements to the OSC RIC, especially xApps that allow for network slice creation. Despite the ProSLICE platform being based on open-source components, the software packages were not available at the time of the work presented in this paper.

The concept of mobile gNBs was explored in [8], where a 5G SA network was implemented using OAI. The solution considers a gNB, on-board a Mobile Robotic Platform, connected to the Core network through a wireless link. To control the position of the mobile gNB, an On-Demand Mobility Management Function was deployed as a Network Function into the Core network, which enables a mobile network operator to monitor the QoS of the radio link established between the UE and the gNB, while manually controlling the position of the Mobile Robotic Platform. Using, for that purpose, the video feed received from the on-board video cameras.

To the best of our knowledge, there are no solutions in the literature that jointly explore the O-RAN architecture and a mobile gNB.

III. Mobility Management xApp

Since we are exploring the O-RAN environment as an enabler for mobile gNBs in real networks, we implemented a function that controls the position of the mobile RAN as an xApp. The proposed Mobility Management xApp collects metrics from the RAN via the Near-RT RIC and implements a novel algorithm able to position the gNB based on those metrics. This allows for the autonomous placement of the mobile RAN to increase the Signal-to-Noise Ratio (SNR) offered to the UE. Among the metrics available from the Mobile RAN via the Near-RT RIC software, we used the SNR to assess the quality of the wireless link established between the gNB and the UE, and the number of transmitted Medium Access Control (MAC) Service Data Units (SDUs). The number of transmitted MAC SDUs makes it possible to determine if a relevant amount of data is being exchanged in the network at each instant.

TABLE I: Definition of the variables used in Algorithm 1

Notation	Definition
$\overline{SNR}$	Average SNR measured in the current position over the last N seconds (e.g., 5 seconds).
A_SNR	Minimum SNR value to consider the channel quality as acceptable.
$P\_\overline{SNR}$	$\overline{SNR}$ value measured in the previous gNB's position before moving the gNB to the current position.
$Threshold$	Difference between $P\_\overline{SNR}$ and $\overline{SNR}$ below which it is not worth changing the gNB positioning.
$t\_Position$	Timestamp when the change of the gNB to the current position happened.
t_Now	Timestamp indicating the current time.
T_1	Maximum value in seconds during which the Mobile Robotic Platform should stay in the current position if the $\overline{SNR}$ value is lower than A_SNR.
T_2	Maximum value in seconds during which the Mobile Robotic Platform should stay in the second position, even if the $\overline{SNR}$ value is higher than A_SNR.
N_SDUs	Number of transmitted DL and UP MAC SDUs in the last N seconds.
$SDU\_Threshold$	Maximum number of MAC SDUs transmitted; it allows to infer the volume of traffic exchanged with the UE.

The proposed algorithm is presented in Algorithm 1, while the definition of its variables is presented in Table I. The proposed algorithm assumes the mobile RAN has two possible positions: 1) a default position, where the gNB is placed when the network is launched; and 2) a second position, which is the targeted gNB's position. The algorithm first checks, in line 1 of Algorithm 1, if the value $\overline{SNR}$ is lower than the minimum acceptable value A_SNR, as well as lower than the $P\_\overline{SNR}$ minus a specific $Threshold$ value. The latter check prevents the Mobile Robotic Platform from moving if the current channel quality is better than the previously recorded channel quality at the last position. The $Threshold$ is necessary because if the $\overline{SNR}$ is only slightly worse than at the previous position, it is not worth moving the Mobile Robotic Platform. If both conditions are met, then the algorithm updates variables and moves the Mobile Robotic Platform to the other position. If the $\overline{SNR}$ is less than A_SNR but still higher than $P\_\overline{SNR}$, the Mobile Robotic Platform remains stationary until T_1 seconds have elapsed, as indicated in line 5. After this time, the Mobile Robotic Platform moves to the other position, as the channel quality there may have improved and has become acceptable during the elapsed time, as a result of changing conditions in dynamic scenarios.

It may be beneficial for the Mobile Robotic Platform

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to return to the default position (e.g., for recharging). As such, in line 9, the algorithm checks if the Mobile Robotic Platform has been in the second position for longer than T_2. Moreover, it determines if the network usage is low, which is assumed if N_SDUs is lower than $SDU\_Threshold$. If these conditions are met, the Mobile Robotic Platform returns to the default position, even if the channel quality is acceptable in the current position. If none of the above conditions are met, the Mobile Robotic Platform remains in its current position.

Algorithm 1 - Algorithm implemented by the Mobility Management xApp.

1: **if** $\overline{SNR} < A\_\overline{SNR}$ **AND** $\overline{SNR} < P\_\overline{SNR} - Threshold$ **then**
2: $P\_\overline{SNR} \leftarrow \overline{SNR}$
3: $t\_Position \leftarrow t\_Now$
4: Move to the other position
5: **else if** $\overline{SNR} < A\_\overline{SNR}$ **AND** $t\_Now - t\_Position > T\_1$ **then**
6: $P\_\overline{SNR} \leftarrow \overline{SNR}$
7: $t\_Position \leftarrow t\_Now$
8: Move to the other position
9: **else if** $t\_Now - t\_Position > T\_2$ **AND** $N\_SDUs < SDU\_Threshold$ **AND** $Current\_Position == Second\_Position$ **then**
10: $P\_\overline{SNR} \leftarrow \overline{SNR}$
11: $t\_Position \leftarrow t\_Now$
12: Move to default position
13: **else**
14: Stay in Position
15: **end if**

IV. System Design and Implementation

The proposed system is composed of three main logical units, as depicted in Figure 1. The unit at the top of Figure 1 is used to deploy the 5G Core network, the Near-RT RIC, and the Mobility Management xApp. The unit at the center of Figure 1 implements the mobile RAN, which consists of the gNB, a Universal Software Radio Peripheral (USRP) Software-Defined Radio (SDR) device, the Mobile Robotic Platform, and the Robotic Control application; the later is used to translate commands from the Mobility Management xApp into movement instructions. A third unit implements the UE software and is connected to another USRP SDR device.

The open-source software package used to implement the Near-RT RIC was Mosaic5G's FlexRIC, which allows to extract measurements from different layers of the 5G protocol stack of the RAN. Moreover, FlexRIC provides an original interface, named E42 [10], which is used to exchange data between the xApps and the FlexRIC; E42 operates similarly to the O-RAN E2 interface. The open-source software package used to implement the 5G network components was OAI [11]. OAI provides all the components required to deploy a 5G SA network, including the RAN and Core Network, and is widely used by the community. Moreover, FlexRIC's developers have created a patch for OAI to implement the E2 interface.

The Core network and FlexRIC were deployed on an *Intel Next Unit of Computing* (NUC) *Board NUC5i5MYBE*. The OAI 5G Core network was deployed using Docker containers. The Mobility Management xApp was deployed in the

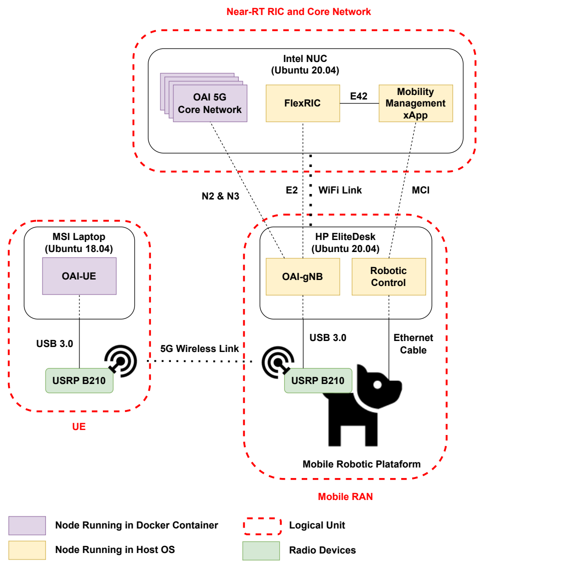

Fig. 1: Architecture of the system designed to implement and evaluate the proposed solution [9].

same computing unit used by FlexRIC, for reduced latency. In order to establish wireless communications between the Core network and the mobile RAN, a Wi-Fi connection was used, due to its ease of implementation, flexibility, and ubiquity. Since since the N2, N3 and E2 interfaces operate under the TCP/IP protocol stack, any wireless communications technology employing the TCP/IP protocol stack can be used.

The gNB was implemented using OAI software running in an HP EliteDesk 800 G2 Small Form Factor (SFF) computer, which was connected to a USRP B210 SDR board [12] via a Universal Serial Bus (USB) 3.0 interface. The USRP B210 employed two W5084K [13] dipole antennas tailored to the 3.6 GHz frequency band. To act as the Mobile Robotic Platform carrying the Mobile RAN, the *Unitree Go1* robot was used, which can be controlled autonomously via user-made applications, such as the developed Robotic Control application. A Mobility Control Interface (MCI) was also developed to exchange data between the Mobility Management xApp and the Robotic Control application. The UE was deployed in a Laptop using a USRP B210 SDR device and two W5084K dipole antennas.

V. System Validation

In order to validate the system, firstly, we assessed the 5G connection performance between the UE and an external data network (DN). For that purpose, we performed a functional test, in which we measured the throughput and Packet Loss Ratio (PLR), using iPerf2. The results are presented in Table II.

To demonstrate the proposed solution, we defined a representative testing scenario in an outdoor environment, which is depicted in Figure 2, considering end-to-end connectivity between the UE and an external DN.

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TABLE II: *iPerf2* results between UE and DN in the proposed testbed.

Connection	DL (Throughput; PLR)	UL (Throughput; PLR)
UDP	22.6 Mbit/s; 8.65%	4.2 Mbit/s; 0%
TCP	3.64 Mbit/s; n/a	4.11 Mbit/s; n/a

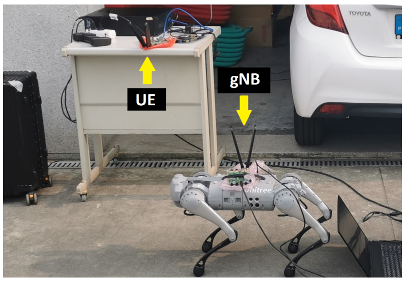

Fig. 2: Outdoor testing environment.

First, we placed the Mobile RAN approximately one meter away from the SDR device connected to the UE. This was defined as the default position of the Mobile RAN, which was set to move parallel to the UE. After initiating the 5G network, UE, and Mobility Management xApp, we placed an obstacle between the two SDR devices as depicted in Figure 3. This obstructed the line of sight between them. Therefore, the Mobile RAN, the Mobility Management xApp detected a reduction in the 5G link SNR to a value lower than the specified A_SNR and sent a control command for the Mobile RAN to move to the second position; this allowed to increase the 5G link SNR above the A_SNR value.

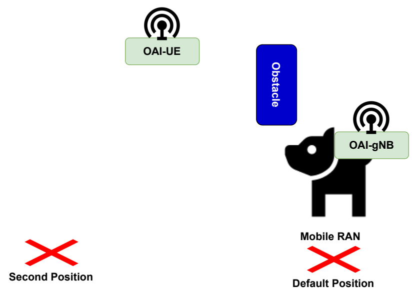

Fig. 3: Diagram depicting the placement of the Mobile RAN, UE, and obstacle, which were considered to assess the proposed solution.

In addition, we considered a second testing scenario, in which we initially placed the Mobile RAN in a default position, further away from the UE. When the Mobility Management xApp was launched, it detected a lower SNR value than A_SNR, due to the increased distance between the SDRs. In order to increase the 5G link's SNR, the Mobility Management xApp sent a control command for the Mobile RAN to move to the second position. The second position, closer to the UE, led to an increase in the SNR value above A_SNR.

VI. Conclusions

We proposed an O-RAN based SA network leveraged on a mobile RAN, which is placed and carried by a Mobile Robotic Platform. Moreover, we proposed a novel Mobility Management xApp, which can collect metrics from the RAN and define the placement of the Mobile Robotic Platform for improved 5G wireless connectivity. The experimental validation carried out allowed us to validate the proposed solution, showing that the Mobility Management xApp allows to take advantage of the O-RAN architecture to autonomously place the Mobile RAN to improve the quality of the 5G wireless link established between the UE and gNB.

As future work, we aim at using improved versions of SDR devices, specifically those that utilize an Ethernet-based fronthaul connection, in order to improve stability and performance. We also aim to develop an improved version of the proposed Mobility Management xApp, considering additional metrics and information, including those obtained by means of computer vision and radio sensing. Moreover, we will consider an Integrated Access and Backhaul (IAB) [14] deployment approach, in order to seamlessly integrate the proposed mobile RAN with existing networks, while using a 5G/6G backhaul link.

References

[1] O-RAN Alliance, *O-RAN Alliance Website*, Accessed on 25-07-2023. [Online]. Available: https://www.o-ran.org/.
[2] M. Polese, L. Bonati, S. D'Oro, S. Basagni, and T. Melodia, "ColO-RAN: Developing Machine Learning-based xApps for Open RAN Closedloop Control on Programmable Experimental Platforms," 2021. DOI: 10.48550/ARXIV.2112.09559.
[3] srsRAN Project, *srsRAN Website*, Accessed on 25-07-2023. [Online]. Available: https://www.srslte.com/.
[4] D. Johnson, D. Maas, and J. Van Der Merwe, "NexRAN: Closed-Loop RAN Slicing in POWDER -A Top-to-Bottom Open-Source Open-RAN Use Case," In *Proceedings of the 15th ACM Workshop on Wireless Network Testbeds, Experimental Evaluation & CHaracterization*, WiNTECH'21, pp. 17–23, New York, NY, USA, 2021. DOI: 10.1145/3477086.3480842.
[5] P. Upadhyaya, A. Abdalla, V. Marojevic, J. Reed, and V. Shah, "Prototyping Next-Generation O-RAN Research Testbeds with SDRs," May 2022. DOI: 10.48550/ARXIV.2205.13178.
[6] R. Schmidt, M. Irazabal, and N. Nikaein, "FlexRIC: An SDK for next-generation SD-RANs," in *Proceedings of the 17th International Conference on Emerging Networking EXperiments and Technologies*, CONEXT 2021, pp. 411–425, Munich, Germany (Virtual Conference), December 2021. DOI: 10.1145/3485983.3494870.
[7] A. Kak, V. -Q. Pham, H. -T. Thieu and N. Choi, "ProSLICE: An Open RAN-based approach to Programmable RAN Slicing," *GLOBECOM 2022 - 2022 IEEE Global Communications Conference*, pp. 197-202, Rio de Janeiro, Brazil, 2022, DOI: 10.1109/GLOBECOM48099.2022.10001497.
[8] D. Maia, "Control and Positioning of a 5G Radio Access Node Deployed in a Mobile Robotic Platform," MSc. Thesis, Faculdade de Engenharia, Universidade do Porto, Portugal, 2022.
[9] G. Queirós, "Autonomous Control and Positioning of a Mobile 5G Radio Access Node Employing the O-RAN Architecture," MSc. Thesis, Faculdade de Engenharia, Universidade do Porto, Portugal, 2023.
[10] FlexRIC, *FlexRIC Wiki*, Accessed on 25-07-2023. [Online]. Available: https://gitlab.eurecom.fr/mosaic5g/flexric/-/wikis/Create-a-xApp.
[11] Open Air Interface, *Open Air Interface Repository*, Accessed on 25-07-2023. [Online]. Available: https://gitlab.eurecom.fr/oai/openairinterface5g.
[12] USRP B210, *USRP B210 Product Page*, Accessed on 25-07-2023. [Online]. Available: https://www.ettus.com/all-products/ub210-kit/.
[13] W5084k Dipole Antenna, *W5084k Dipole Antenna Datasheet*, Accessed on 25-07-2023. [Online]. Available: https://www.farnell.com/datasheets/3812050.pdf.
[14] NR; NR and NG-RAN Overall description; Stage-2, 3GPP TS 38.300 V16.10.0, September 2022.

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