Achieving Energy Efficiency in Open Radio Access Networks (ORAN) using xApps

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***Abstract*—Open Radio Access Networks (ORAN) have emerged as a transformative approach to building flexible and modular wireless networks. The disaggregated architecture of ORAN enables the development and deployment of innovative applications, known as xApps, which play a crucial role in optimizing network performance and energy efficiency. This paper explores the potential of xApps in achieving energy efficiency in**

ORAN and examines the challenges faced by developers in this context. We investigate the available open platforms for xApps development and testing, highlighting their features and limitations. Furthermore, we delve into the specific strategies employed by energy-efficient xApps, such as dynamic resource allocation, sleep mode management, and intelligent traffic steering.

The paper also emphasizes the importance of standardization efforts and collaboration among stakeholders to establish best practices for xApps development and deployment.

***Keywords*—** *Open Radio Access Network (ORAN), xApps, Energy Efficiency, RAN Intelligent Controller (RIC), Software-Defined Networks, Wireless Networks, 5G*

I. INTRODCUTION

As 5G expands worldwide, it's bringing along a hefty increase in energy needs for radio access networks. This is because 5G relies on high-frequency waves that don't travel as far, meaning we need more radio units to cover the same area. But transmitting those waves eats up a lot of energy [1]. So, to tackle this, we can create x-Apps to save energy in several ways.

The subsequent section of this paper presents an introduction to the key concepts and architecture related to ORAN.

1. Basic Terminologies

1.1 Radio Access Network (RAN)

Most mobile communication pertaining to phone calls and wireless internet access is handled via a RAN. User Equipment (UE), such as phones or laptops, connects to a base station responsible for facilitating a connection between the UE and a Core Network (CN), which in turn can connect to external networks to let the UE make phone calls, send text messages, or access the internet [2].

Macro base stations provide RAN coverage to large areas and are achieved via the utilization of large towers and antennas combined with lower frequency radio waves. Micro base stations provide additional network capacity to small areas and are required in areas that encounter heavy traffic, such as malls and airports. Radio transmitters are the most abundant yet costly components within a RAN in terms of power consumption. Studies show that base station power consumption constituted about 80% of RAN energy use [3].

With 5G, base stations have evolved into a disaggregated architecture, namely - Control Unit (CU), Distributed Unit (DU), and Radio Unit (RU) [4].

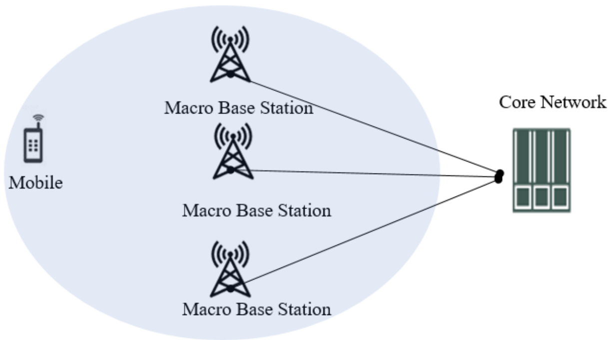

Figure 1: Radio Access Network

1.2 ORAN – Open Radio Access Network

O-RAN (Open RAN) architecture enhances vRAN by introducing clear interfaces between the Distributed Unit (DU) and Radio Unit (RU). Previously, CSPs relied on single vendor RAN equipment to ensure compatibility, as DU-RU interfaces were vendor-specific.

O-RAN's standardized DU-RU interfaces enable network components (CUs, DUs, and RUs) to become vendor-agnostic [2]. This vendor-agnostic approach promotes interoperability and flexibility within the network ecosystem. CSPs can now mix and match components from different vendors, fostering competition and innovation.

1.3 RAN Intelligent Controller (RIC)

RIC enhances automation and orchestration within the network [6]. RICs enforce predetermined policies, like traffic prioritization for specific customers, improving service quality.

Two types of RICs exist: near-Real-Time (near-RT) -operate within milliseconds to seconds, directly communicating with network components to enforce policies; and non-Real-Time (non-RT)- operate beyond one-second intervals, configuring and optimizing policies for near-RT RICs [7].

RICs' policies and functionalities are governed by applications called xApps (near-RT) and rApps (non-RT). These applications leverage O-RAN-specified interfaces for RAN monitoring and control [8].

1.4 xApps

xApps are specialized software modules that work in conjunction with the RIC, a central software component of the Open RAN architecture, to efficiently manage and optimize network functions in near-real time. These applications enable the RIC to dynamically adapt to changing network conditions and make intelligent decisions to enhance RAN performance.

By utilizing xApps, the RIC can effectively control and fine tune various aspects of the RAN, ensuring optimal resource allocation and improved user experience. The RIC serves as the brain of the Open RAN system, overseeing the overall operation and optimization of the network, while xApps act as smart tools that execute specific

2. Architecture of Near-RT RIC

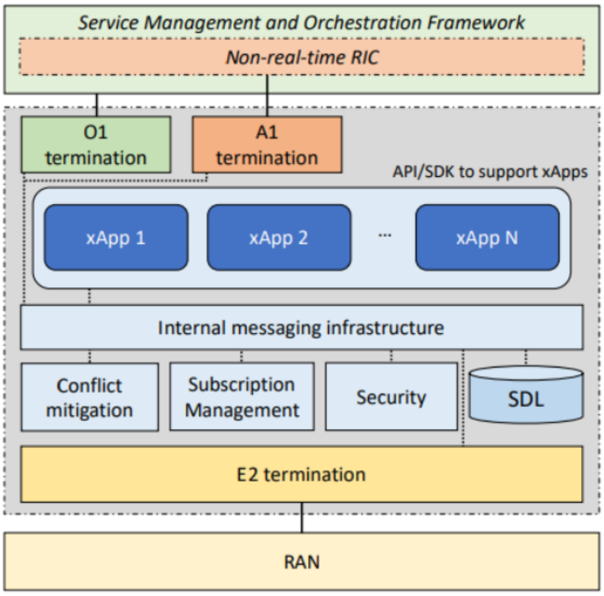

Figure 2: Near-RT RIC Architecture

The near-RT RIC is a sophisticated system designed to enhance the efficiency and performance of radio access networks (RAN). It consists of several key components:

Internal Messaging System: This serves as communication backbone, linking various applications (xApps), services, and interfaces. It's not tied to a specific technology but must fulfill certain functions like endpoint registration, message sending and receiving, and ensuring data integrity.

Conflict Resolution: A crucial mechanism that resolves disagreements between xApps, which may inadvertently counteract each other's optimizations. It works by either preemptively deciding which xApp's configuration takes precedence or by reviewing the system's performance after changes have been made.

Subscription Management: This feature allows xApps to tap into the E2 interface functionalities. It manages their access to messages and consolidates similar subscription requests to streamline communication.

Security Framework: Still under development, this aims to protect the RAN from potential threats posed by malicious xApps, such as data breaches or performance issues.

Data Repositories: The system includes two databases: the RAN Information Base (R-NIB) and the User Equipment Information Base (UE-NIB). The R-NIB holds details about the E2 nodes, while the UE-NIB tracks user identities across different nodes. Access to this data is provided through a Shared Data Layer (SDL) API.

xApp Lifecycle Management: Near-RT RIC automates the entire lifecycle of xApps, from their introduction to the system to their eventual retirement. This process is supported by a set of tools for monitoring and managing system health and performance.

These components work in tandem to ensure the RIC operates smoothly, effectively managing the RAN's resources and user demands. The system's architecture is designed to be robust and adaptable, ready to meet the challenges of modern network management.

The Rise of 5G and Its Energy Consumption Challenges 5G expansion leads to a substantial increase in energy consumption for radio access networks, presenting a critical challenge for network operators to balance improved performance with energy efficiency [1].

The Evolution of ORAN Architecture and the Importance of Energy Efficiency the Open Radio Access Network (ORAN) architecture promotes disaggregation of hardware and software components, enabling flexibility, scalability, and cost-effectiveness compared to traditional RAN architectures [2, 3].

Energy efficiency is paramount in modern telecommunication networks to reduce operational costs and environmental impact. ORAN presents challenges and opportunities for achieving energy efficiency through efficient resource management and coordination [4, 5].

Regulatory Requirements, Sustainability Goals, and the Role of xApps in ORAN Energy Efficiency Regulatory requirements and sustainability goals put pressure on network operators to adopt energy-efficient solutions, making it a top priority for the telecommunications industry [6]. xApps play an essential purpose in the ORAN architecture by enabling third-party developers to create applications that interact with and control network components. By leveraging open interfaces and APIs, xApps can implement advanced energy saving techniques, such as intelligent scheduling, power management, traffic optimization, and resource allocation strategies [7, 8].

Section 1 introduces the topic, while section 2 showcases various xApp examples. Section 3 focuses on xApp development frameworks, and section 4 examines case studies and real-world implementations. Sections 5, 6, and 7 explore future applications and use cases of energy-efficient xApps, limitations in their development and deployment, and future research directions and opportunities, respectively. Finally, section 8 presents the conclusion.

II. DEMONSTRATING XAPP CAPABILITIES

xApps can be categorized based on their functionality and the specific aspects of energy efficiency they target. Some common characteristics of energy-efficient xApps include:

1. **Power Management xApps:** These xApps focus on optimizing the power consumption of RAN components, such as RUs and DUs. They implement techniques like dynamic power scaling, sleep mode management, and energy-aware resource allocation to reduce energy consumption during periods of low traffic or idle time [9]. For example, an xApp can dynamically adjust the transmit power of RUs based on the traffic load, reducing power consumption during off-peak hours.
2. **Traffic Optimization xApps:** Traffic optimization xApps aim to efficiently manage and route network traffic to minimize energy consumption. They employ techniques such as load balancing, traffic consolidation, and intelligent routing to minimize the total energy footprint of the network [10]. These xApps can dynamically distribute traffic across multiple RUs or DUs to balance the load and minimize energy consumption.
3. **Spectrum Efficiency xApps:** These xApps focus on optimizing the use of radio spectrum to improve energy efficiency. They implement techniques like dynamic spectrum allocation, cognitive radio, and interference management to maximize the spectral efficiency and reduce the energy consumed per bit of data transmitted [11]. By intelligently allocating spectrum resources based on traffic demands and network conditions, these xApps can minimize energy waste and improve overall network efficiency.
4. **Cooling and Temperature Management xApps:** Cooling systems are responsible for a substantial amount of the total energy consumed in RAN infrastructure. Cooling and temperature management xApps optimize the cooling strategies based on the actual temperature and workload conditions, reducing unnecessary energy waste [12]. These xApps can dynamically adjust the cooling parameters, such as fan speed or temperature thresholds, based on real-time monitoring of the RAN components.
5. **KPI Monitoring xApps:** These xApps gather radio and system Key Performance Indicators (KPIs) from E2 Nodes and store them in the Shared Data Layer (SDL). The collected KPIs can include metrics such as UE measurements, E2 Node measurements, and E2 Node load-related measurements. KPI monitoring xApps provide valuable data for other xApps to make informed decisions and optimize energy efficiency based on real-time network conditions [14]. For example, they can monitor the power consumption of RUs and provide insights for power management xApps to take appropriate actions.
6. **QoE Prediction xApps:** QoE prediction xApps generate throughput predictions for UEs in different cells. They utilize machine learning algorithms and data from the UE-Metric and Cell-Metric namespaces in the SDL to predict the expected throughput of a UE in the serving and neighboring cells. These predictions are used by other xApps, such as traffic steering xApps, to make informed decisions about UE handovers and optimize energy efficiency [15]. By predicting the QoE of UEs, these xApps can proactively optimize network resources and minimize energy consumption while maintaining a high quality of service.
7. **Anomaly Detection xApps:** Anomaly detection xApps monitor UE metrics and identify anomalous behavior that may impact energy efficiency. They regularly fetch UE data from the SDL and employ algorithms to detect patterns and anomalies. Once an anomaly is detected, these xApps can trigger actions in other xApps, such as traffic steering xApps, to optimize network performance and energy efficiency [16]. By promptly identifying and addressing anomalies, these xApps can prevent energy waste and ensure the smooth operation of the network. By combining xApps from different categories, network operators can create a holistic approach to energy efficiency, optimizing various aspects of the network simultaneously.

III. XAPP DEVELOPMENT FRAMEWORKS AND PLATFORMS

Several frameworks and platforms have been proposed to facilitate the development of xApps, which are crucial for achieving energy efficiency in ORAN. The O-RAN Software Community (OSC) xApp Framework is an open-source initiative that provides a standardized environment for developing and deploying xApps [21]. It offers APIs and libraries that allow developers to access and control various aspects of the RAN, ensuring compatibility and interoperability among different xApps.

The Open Networking Foundation (ONF) has developed the SD-RAN xApp Framework, which provides a platform for creating and deploying xApps in a software-defined RAN environment [22]. It leverages the principles of software defined networking (SDN) to provide a flexible and programmable platform for xApp development.

The RIC Platform is a key component of the ORAN architecture that hosts and manages xApps [23]. It provides a standardized environment for deploying and executing xApps, enabling them to interact with the RAN components and optimize network performance. The RIC Platform offers APIs and interfaces for xApp integration and management, acting as a centralized hub for xApp orchestration.

IV. CASE STUDIES AND LIMITATIONS

1. QACM - QoS-Aware xApp Conflict Mitigation in Open RAN Overview

The QACM (QoS-Aware Conflict Mitigation) method is a significant advancement in Open RAN technology. It addresses the challenge of intra-component conflict mitigation among Extended Applications (xApps) in the Near Real Time RAN Intelligent Controller (Near-RTRIC). The QACM method optimizes the configuration of conflicting parameters to maximize the number of xApps meeting their Quality of Service (QoS) requirements.

Results: The case study demonstrates that QACM outperforms benchmark methods in maintaining the QoS threshold of involved xApps. Four unique case studies were conducted, covering conflicting cases considering two or more involved xApps and methods for handling different types of conflicts.

2. Mavenir's AI-Powered, Closed-Loop Near-RT RIC Overview

Mavenir showcased the world's first O-RAN standards compliant Near-RT RIC with an AI-powered extensible application (xApp) during the O-RAN India plugfest 2021. This xApp controls the traffic steering functionality of a 5G Radio Access Network (RAN), crucial for managing user connectivity and mobility.

Results: Mavenir's Traffic Steering xApp leveraged live data reports from the RAN and harnessed Network Intelligence-asa-Service (NIaaS) from Mavenir's Near-RT RIC platform. It optimized mobility control decisions for users in the RAN using an online reinforcement learning engine. The xApp significantly improved RAN performance, reducing network overhead by more than 50% and increasing cell-edge capacity and user throughput by over 20%.

3. Increasing Energy Efficiency of O-RAN through Utilization of xApps

Overview: Fredrik Borg's dissertation presents a comprehensive study on enhancing the energy efficiency of Open RAN (O-RAN) by leveraging xApps. The research focuses on the potential energy savings in Radio Units (RUs) and the implementation of prototype xApps to achieve this goal. The study is grounded in the context of 5G networks' increased energy consumption due to the need for more RUs to compensate for the high-frequency radio waves' shorter effective range1.

Methodology: The dissertation outlines a simulated RAN Intelligent Controller (RIC) environment where the prototype xApps are deployed. It includes a detailed discussion on the handover prediction algorithm and the interaction flow between the xApps and the RIC1.

Results: Through simulation runs with and without xApp utilization, the study demonstrates a potential 20-35% decrease in energy consumption among RUs. The dissertation provides a direct comparison of baseline simulation runs and those enhanced with xApp utilization, highlighting the effectiveness of the implemented prototype xApps in reducing energy consumption, especially under high traffic load conditions.

4. Dynamic Spectrum Allocation in OpenRAN Networks

Overview: The paper discusses a novel approach to dynamic spectrum allocation in OpenRAN networks, which is crucial for addressing the problem of limited and inefficiently used radio resources. The authors propose a multi-source mechanism that adjusts the occupied frequency bands dynamically, utilizing data from various sources beyond just radio-related information.

Methodology: The proposed system collects contextual information from ubiquitous sources, such as city monitoring, to identify areas with high or low expected traffic. This allows for a more efficient allocation of spectrum resources, ensuring quality of service while improving spectral efficiency.

Results: The implementation of the proposed algorithm in a simulated environment showed that it is possible to reduce the spectrum used with only a slight reduction in user bitrate. This leads to an increase in the spectral efficiency of the entire system. The paper presents simulation results that validate the effectiveness of the proposed multi-source context information system in dynamic spectrum allocation.

5. Challenges and Limitations of Existing Solutions:

Energy-efficient xApps have shown promising results, but there are still challenges and limitations associated with existing solutions that need to be addressed for their successful deployment and widespread adoption.

One of the primary challenges is managing conflicts between multiple xApps [48]. As the number of xApps in an ORAN network grows, the potential for conflicts in resource allocation, configuration, and optimization decisions increases. Developing sophisticated coordination mechanisms and conflict resolution strategies is crucial to ensure the harmonious operation of multiple xApps.

Ensuring interoperability across different ORAN implementations is another significant challenge [49]. The open and disaggregated nature of ORAN allows for the participation of multiple vendors, but differences in hardware, software, and interfaces can lead to compatibility issues and hinder the smooth deployment and operation of xApps.

Extensive testing and validation of xApps in real-world environments is also necessary [50]. The complexity and variability of real-world network conditions make it challenging to adequately test xApps in laboratory settings. Field trials and real-world validation are essential to assess the behavior and effectiveness of xApps under diverse traffic patterns, network topologies, and environmental factors.

The limited availability of standardized interfaces and APIs poses another challenge [51]. Standardized interfaces and APIs are crucial for the seamless integration and communication of xApps with other network components. While organizations like the O-RAN Alliance are working towards defining these standards, the current landscape still lacks complete and mature specifications, hindering the development of interoperable and portable xApps. Scalability and performance challenges in large-scale deployments are also concerns [52]. As ORAN networks grow in size and complexity, xApps must be able to handle large volumes of data, process real-time network events, and make timely decisions. Ensuring the efficient operation of xApps while maintaining low latency, high throughput, and minimal resource overhead is crucial for their successful deployment in commercial ORAN networks.

Finally, security and privacy considerations need to be addressed [53]. The open nature of ORAN and the involvement of third-party xApps introduce new security and privacy challenges. Ensuring the security and integrity of xApps, protecting sensitive data, and preventing unauthorized access or tampering are critical considerations that require robust security measures and best practices.

V. FUTURE APPLICATIONS AND USE CASES OF ENERGYEFFICIENT

XAPPS

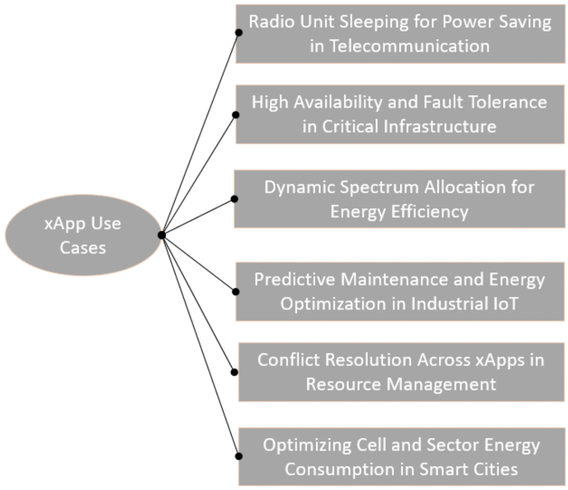

Figure 3: Industrial uses of xApps

1.
2. Radio Unit (RU) Sleeping Power Saving in Telecommunications In the telecommunication industry, xApps can intelligently manage the sleep mode of radio units (RUs) to achieve significant power savings. During periods of low network traffic or off-peak hours, xApps can dynamically instruct specific RUs to enter a low-power sleep state [40]. This approach allows the network to conserve energy while maintaining essential coverage and connectivity. By leveraging the real-time monitoring and control capabilities of xApps, network operators can optimize the energy consumption of their RAN infrastructure without compromising user experience.

3. Optimizing Cell and Sector Energy Consumption in Smart Cities In the context of smart cities, energy-efficient xApps can play a vital role in optimizing the energy consumption of cell sites and sectors. By analyzing real-time data from the network, xApps can dynamically adjust transmit power levels, turn off unused components, or even put certain cells or sectors into sleep mode during low-traffic hours [43]. This intelligent management of network resources can save energy and contribute to the overall sustainability goals of smart city initiatives. Additionally, xApps can enable the integration of renewable energy sources, such as solar or wind power, into the RAN infrastructure, further reducing the reliance on fossil fuels.

4. Predictive Maintenance and Energy Optimization in Industrial IoT Energy-efficient xApps can be applied in the realm of Industrial Internet of Things (IIoT) to enable predictive maintenance and energy optimization. By collecting and analyzing data from various sensors and devices in industrial settings, xApps can identify patterns and anomalies that indicate potential equipment failures or inefficiencies [44]. This predictive capability allows for proactive maintenance, reducing downtime and extending the lifespan of industrial assets. Moreover,

xApps can optimize the energy consumption of industrial processes by dynamically adjusting operational parameters based on real-time conditions and production requirements.

5. Dynamic Spectrum Allocation for Energy Efficiency xApps can leverage multi-source context information to enable dynamic spectrum allocation in OpenRAN networks [45]. By intelligently assigning frequency bands based on real-time network conditions and user demands, xApps can optimize spectrum utilization and reduce energy consumption. This dynamic approach ensures that the available spectrum is used efficiently, minimizing wastage and reducing the overall energy footprint of the network.

VI. FUTURE DIRECTIONS AND RESEARCH OPPORTUNITIES

The development of energy-efficient xApps in ORAN presents a wide range of research opportunities and future directions. Advanced machine learning techniques, such as deep learning algorithms like convolutional neural networks (CNNs) and recurrent neural networks (RNNs), can enable more sophisticated and adaptive energy-saving strategies in ORAN [56].

These techniques can leverage vast amounts of network data to learn complex patterns and make intelligent decisions for energy efficiency. Developing lightweight and computationally efficient ML models that can run on resource-constrained RAN components is crucial for enabling real-time energy-saving decisions.

Multi-objective optimization frameworks that simultaneously consider energy efficiency, spectral efficiency, and latency are essential to achieve a balance between energy savings and network performance [57]. Researchers should investigate multi-objective evolutionary algorithms and Pareto optimization techniques to handle the trade-offs between these conflicting objectives effectively.
Collaborative energy management strategies, such as distributed learning techniques for energy optimization across multiple xApps and network nodes, can enhance the overall energy savings of the network [58]. Exploring game-theoretic approaches and multi-agent reinforcement learning techniques to model and optimize the interactions between xApps for energy efficiency is a promising research direction. Integrating edge computing and multi-access edge computing (MEC) in ORAN deployments can enable more efficient processing and reduce the energy overhead associated with data transmission to centralized locations [59]. Designing energy-efficient xApps that can leverage the capabilities of edge computing and optimize energy consumption at the network edge is a key research area.

Establishing large-scale testbeds and conducting real-world deployments in operational networks are necessary to evaluate the performance of xApps under various network conditions and traffic scenarios [62]. These efforts provide valuable insights into the practical challenges and benefits of deploying energy-efficient xApps in ORAN.

Exploring the integration of energy-efficient xApps with advanced antenna systems, such as massive MIMO and beam forming techniques, and hardware innovations, such as energy-efficient power amplifiers and adaptive antenna systems, can further enhance the energy performance of ORAN [63].

VII. CONCLUSION

In this review paper, we have explored the potential of xApps in achieving energy efficiency in Open Radio Access Networks (ORAN). We have examined the various strategies employed by energy-efficient xApps, such as dynamic resource allocation, sleep mode management, and intelligent traffic steering, highlighting their effectiveness in reducing the overall energy footprint of the network. Case studies and practical implementations have shown significant reductions in energy consumption, ranging from 12% to 20% in various deployments. Furthermore, integrating xApp-defined traffic steering into an O-RAN compliant network can enhance energy efficiency by up to 35%.

Future research opportunities for energy-efficient xApps include developing more adaptive and intelligent xApps that can dynamically optimize energy efficiency based on realtime network conditions and user demands. Our future work will focus on developing a novel xApp that incorporates advanced algorithms to enable autonomous and dynamic optimization of energy efficiency in ORAN, working seamlessly with the RAN Intelligent Controller (RIC) and other ORAN components.

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