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Energy Efficiency And Fault Tolerance In Open RAN And Future Internet

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***Abstract*—Open Radio Access Networks (Open RAN) represent a promising technological advancement within the realm of the future internet. Research efforts are currently directed towards enhancing energy efficiency and fault tolerance, which are critical aspects for both Open RAN and the future internet landscape. In the context of energy saving in Open RAN, there exists a spectrum of methods for achieving energy efficiency. These methods include the toggling of on/off states for different hardware resources such as base station units, distributed units, and radio units. Conversely, for enhancing fault tolerance in Open RAN, Software-Defined Networking (SDN) and OpenFlow based techniques of restoration and path protection using in-band control methods can be implemented. In this paper, we provide an overview of Open RAN and our view on achieving energy efficiency and fault tolerance within Open RAN. Furthermore, we implement one of our proposed energy-saving techniques and provide an overview of the results achieved. Specifically, we introduce a dynamic CPU scheduling algorithm designed to optimize energy consumption by dynamically toggling CPU cores on and off while ensuring that sufficient CPU cores remain active to maintain computational performance. Our preliminary emulation studies demonstrate energy savings across various load scenarios.**

***Index Terms*—Open RAN, SDN, OpenFlow**

I. Introduction

The competition among network operators in the industry is intensifying rapidly as the demand for network traffic is constantly on the rise which creates a very severe situation for network operators to manage capital expenditure (CAPEX) and operational expenditure (OPEX) effectively. The Open Radio Access Network (Open RAN) concept is gaining a lot of popularity in the area of telecommunication networks [1]. Open RAN helps in solving a significant challenge for network operators which is the rising cost of building and running networks. Open RAN embraces open standards and software-centric approaches, allowing operators to dis-aggregate network components and promote interoperability among various vendors. Also, Open Air Interface (OAI) plays a pivotal role as an open-source platform that facilitates the development and testing of innovative wireless technologies, serving as a crucial driver for the evolution of Open RAN. Together, these initiatives aim to foster greater flexibility, scalability, and innovation in next-generation wireless networks while reducing dependency on proprietary hardware and closed ecosystems.

Open RAN systems are versatile and have the potential to enhance network capacity because of the dis-aggregation concept and diversity of hardware. This versatility does come at a cost which is increased energy consumption. Optimizing the energy footprint with rapidly increasing wireless network demands is becoming a topic of concern, not only for energy-saving but also for reducing environmental impact. Ensuring the continuous availability and reliability of Open RAN networks is another important aspect of deploying them successfully. So developing reliable fault tolerance techniques for Open RAN is crucial. In this paper, we explore the various challenges of achieving energy efficiency and fault tolerance in Open RAN. To realize this goal and overcome the challenges we propose to use the concept of SDN and Open Flow by implementing restoration and protection in-band control methods for realizing the goal of fault tolerance in Open RAN. Also, by proposing a CPU scheduling algorithm method we aim to solve the problem of energy efficiency on the gNodeb side which can face power budget issues in remote locations.

The paper is structured as follows: Section II presents energy efficiency challenges in Open RAN. Section III provides fault tolerance challenges in Open RAN. Section IV provides details about proposed method for Open RAN challenges. Section V we show the preliminary results of our proposed energy saving algorithm. Finally, Section VI concludes the paper by summarizing challenges, proposed solutions and suggesting potential future work on fault tolerance in Open RAN.

II. Energy Efficiency Challenges In Open RAN

Open RAN is very important concept, because of its dis-aggregation feature, which involves separation of RAN in to three logical nodes: Open Control Unit(O-CU), Open Distributed Unit(O-DU) and Open Radio Unit(O-RU) thus improving ability to use and integrate equipment and functionality from various vendors. Open RAN thus helps the vendors to reduce operational costs, and environmental impact and ensure sustainability in future telecommunication networks. Open RAN does provide lots of benefits, but in terms of achieving energy efficiency in Open RAN, lots of challenges do exist. The common problems and challenges for power consumption and faul tolerance as shown in Figure 1. Open RAN is implemented using General Purpose Processors (GPP) servers and Commercial Off-The-Shelf (COTS) hardware, along with software applications that virtualize network services. Open

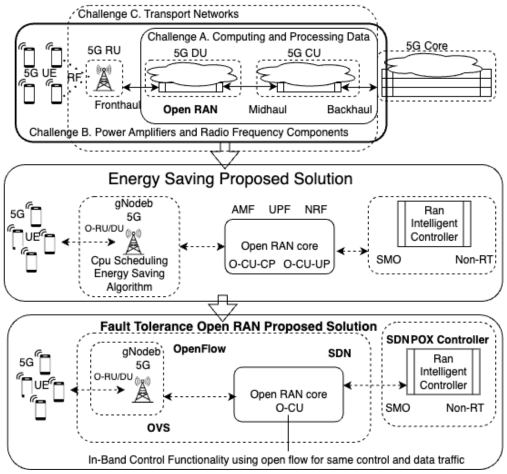

Fig. 1. Open RAN Challenges-Energy Saving and Fault Tolerance Solution

RAN networks significant power consumption can be divided into three categories [1]–[3]:

A. Computing And Processing Data

A significant hardware challenge arises from the substantial computational demands of data processing and network function virtualization, which occur within cloud and edge servers housing Centralized Units (CUs) and Distributed Units (DUs). To minimize energy consumption, it is essential to optimize the efficiency of these computing resources.

B. Power Amplifiers And Radio Frequency Components

The functioning of Radio Frequency (RF) components and power amplifiers in the Radio Units (RUs) is a crucial factor influencing power consumption in Open RAN. These parts can be power-intensive but are essential for sending and receiving messages. Balancing RF performance with energy efficiency is also an ongoing hardware challenge. The radio network is composed of several key elements, including the central processing units (CPUs), accelerators, and network interface cards (NIC). The hardware and software that are used to implement CUs, DUs, and RUs collectively consume more power than the radio network as a whole. The placement of the CUs, DUs, and RUs on the network nodes also has an impact on the radio network's power usage. Since the CUs, DUs, and some portions of the RUs are implemented using virtual machines on COTS servers because of Open RAN use of network virtualization, the GPPs computational overhead accounts for the majority of the radio unit's energy usage.

C. Transport Networks

Another critical factor contributing to power consumption is the transportation of data. This involves the movement of data across back-haul, mid-haul, and front-haul links, which constitute the fundamental components of the transport network. Within transport network, power is consumed by critical components such as switches, transponders, and multiplexers. The choice of transport technology varies based on factors like network topology, capacity requirements, and the number of connections between CUs, DUs and RUs. These transport technologies include a range of options, including Ethernet, microwave radio, passive optical network (PON), point-to-point (P2P) fibre, and coarse wavelength division multiplexing (CWDM). The optimisation of energy utilisation in Open RAN deployments is a complex task because each technology introduces its own set of power consumption considerations.

III. Fault Tolerance Challenges In Open RAN

At the core of the Open RAN architecture specified by the O-RAN Alliance lies the RAN Intelligent Controller (RIC). O-RAN defines two distinct RIC categories: the non-real-time (Non-RT) RIC and the near-real-time (Near-RT) RIC. The capability of the Non-RT RIC falls within the larger context of service management and orchestration (SMO).Within this framework, the Non-RT RIC is granted access to a range of services. These services cover activities like gathering data from various nodes located within the O-RAN architecture and providing services to these nodes. The SMO, therefore, serves as the gateway through which the Non-RT RIC interfaces with the various components of the O-RAN network, ensuring efficient coordination and management of services and data across the network infrastructure.

The fault tolerance system should urgently meet stringent Service Level Agreement (SLA) criteria while providing the smooth integration of the whole network infrastructure in the context of Open RAN-based 5G and beyond 5G networks. The problem is made worse by the underlying heterogeneity of network components and the addition of non-standard features, which significantly raise the complexity and volume of network problems. To effectively address this, there is a clear need for an advanced fault tolerance methodology. Such a methodology must possess the capability to integrate dynamic fault recovery, troubleshoot, mitigate, and perform root cause analysis for faults within the Open RAN ecosystem. This evolution in fault tolerance is essential to maintain the high-performance standards expected in modern telecommunications networks [4].

IV. Our Proposed Solution For Open RAN Challenges

A. Proposed Solution For Energy Efficiency In Open RAN

In the previous section, we discussed about various challenges for energy efficiency in Open RAN. Our proposed solution specifically targets energy efficiency at the gNodeb. Remote gNodeb's in rural areas frequently struggle with limited availability to power and are required to follow stringent power budgets. Our goal is to make the gNodeb more energy-efficient so that it can operate within its power constraints without noticeably degrading performance. To do this, we propose to implement a CPU scheduling algorithm that can be implemented at the gNodeb side improving the power efficiency, refer Figure1.

The CPU scheduling algorithm operates by examining the different tasks running on the gNodeb. It assesses how many

CPU cores are actively handling these tasks. Subsequently, it dynamically adjusts the number of active cores based on the CPU's workload. When the workload decreases and falls below a certain threshold, the algorithm transitions the CPU core into a sleep mode, thereby conserving energy. When the workload exceeds a predefined threshold, the core state switches to active, ensuring that resources are readily available. The algorithm efficiently manages the state of CPU cores, adapting to changing workloads. Our algorithm's objective is to dynamically transition between sleep and active states based on workload conditions, ultimately conserving power.

B. Proposed Method For Fault Tolerance In Open RAN

Our proposal aims to enhance the fault tolerance and resilience of Open Radio Access Network (RAN) by implementing OpenFlow and Software-Defined Networking (SDN) technologies [8], refer Figure 1 in which we combine O-CU-CP and O-CU-UP in to one plane for transferring both control and data traffic. We do this by implementing restoration and path protection mechanisms outlined in [6] and [7], along with the extended functionalities related to in-band control methods and queuing in OpenFlow switches as elaborated in [5]. In network restoration method an alternative path is established in response to a failure occurrence. In the case of path protection, a separate, disjoint alternative path is pre-established before any potential failure, and upon detecting a failure, traffic is promptly rerouted onto this alternative path. In the restoration method, loss-of-signal (LOS) detection proves advantageous, as it possesses the capability to identify failures across all forwarding ports [5]. These enhancements collectively contribute to expedited recovery in Open RAN environments.

V. Preliminary Results

In our preliminary results we implemented energy saving algorithm on Powder test-bed situated in USA. We configured open ran by deploying 3 UEs, 1 Gnodeb and 1 core network using docker containers and open air interface 5G software [9]. Preliminary results show that implementing the proposed CPU scheduling algorithm helps to achieve energy saving at gNodeb side. Tests were performed for both TCP and UDP traffic and for varying link capacities from 500Mbps to 4000Mbps. As the link capacities is increased, more energy saving gains are observed. Energy saving gains for UDP are more than that for TCP, refer Figure 2.

VI. Conclusion

In this paper, we have discussed about three primary challenges associated with energy-saving like computing and data processing, power amplifiers, radio frequency components and transport networks. We have also discussed the need for fault-tolerant systems to swiftly meet Service Level Agreement (SLA) targets for Open RAN-based 5G and beyond 5G networks. To tackle these challenges, we have proposed the implementation of a CPU scheduling algorithm at the gNodeb side to enhance energy efficiency. Furthermore, we have proposed SDN based restoration and path protection in-band control strategies to achieve fault tolerance in Open RAN. We made use of POWDER test-bed to emulate the real world scenario of implementing CPU scheduling algorithm for energy saving. In our preliminary experimentation results the proposed CPU scheduling algorithm achieved energy saving for various link capacities. This was tested by running UE, gNodeb and core network using open air interface 5G software on a single compute node by separating the functions and services using docker containers. Our future work will focus on the implementation of fault tolerance mechanisms in Open RAN, using the POWDER test-bed as our testing environment. We intend to achieve this by incorporating Software-Defined Networking (SDN) and OpenFlow based techniques of restoration and path protection using in-band control methods discussed in this paper.

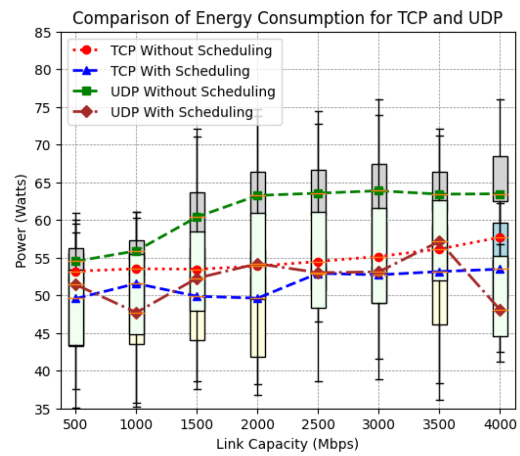

Fig. 2. Energy Saving using CPU Scheduling Algorithm

VII. Acknowledgement

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