Enhancing Open RAN Digital Twin Through Power Consumption Measurement

Ahmed Al-Tahmeesschi*, Yi Chu*, Josh Shackleton,
Swarna Chetty, Mostafa Rahmani, David Grace and Hamed Ahmadi
School of Physics Engineering and Technology, University of York, United Kingdom

***Abstract*—The increasing demand for high-speed, ultra-reliable and low-latency communications in 5G and beyond networks has led to a significant increase in power consumption, particularly within the Radio Access Network (RAN). This growing energy demand raises operational and sustainability challenges for mobile network operators, requiring novel solutions to enhance energy efficiency while maintaining Quality of Service (QoS). 5G networks are evolving towards disaggregated, programmable, and intelligent architectures, with Open Radio Access Network (O-RAN) spearheaded by the O-RAN Alliance, enabling greater flexibility, interoperability, and cost-effectiveness. However, this disaggregated approach introduces new complexities, especially in terms of power consumption across different network components, including Open Radio Units (RUs), Open Distributed Units (DUs) and Open Central Units (CUs). Understanding the power efficiency of different O-RAN functional splits is crucial for optimising energy consumption and network sustainability. In this paper, we present a comprehensive measurement study of power consumption in RUs, DUs and CUs under varying network loads, specifically analysing the impact of Physical resource block (PRB) utilisation in Split 8 and Split 7.2b. The measurements were conducted on both software-defined radio (SDR)-based RUs and commercial indoor and outdoor RU, as well as their corresponding DU and CU. By evaluating real-world hardware deployments under different operational conditions, this study provides empirical insights into the power efficiency of various O-RAN configurations. The results highlight that power consumption does not scale significantly with network load, suggesting that a large portion of energy consumption remains constant regardless of traffic demand.**

***Index Terms*—O-RAN, Open RAN, Energy Efficiency, Test Methodology, Digital Twin, RU**

I. Introduction

The exponential growth in data demand, driven by emerging applications such as Immersive Communications (ICs) [1], vehicle-to-everything (V2X) communication and other data-intensive use cases, has significantly escalated the power consumption of mobile networks [2]. Next-generation mobile networks must support these computationally intensive applications while ensuring energy-efficient operation.

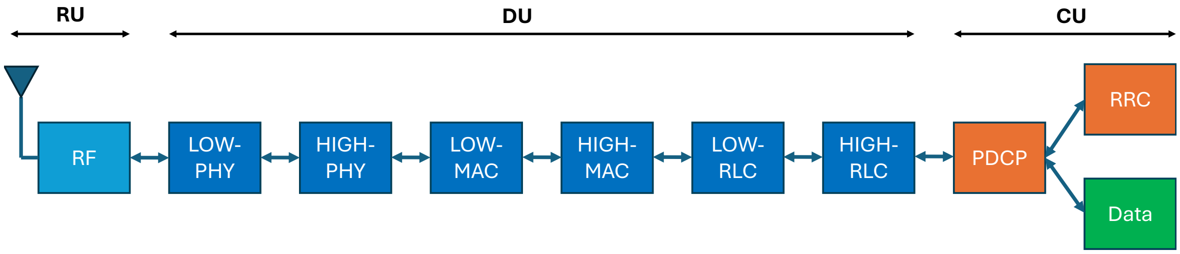
With Fifth Generation (5G) and beyond networks transitioning towards a more open, disaggregated, and virtualised approach to Radio Access Network (RAN) design due to its flexibility interoperability and potential cost efficiency [3] the Open RAN paradigm, driven by the O-RAN Alliance, is poised to significantly impact RAN deployment and management. The disaggregation of the RAN into distinct network functions, namely the CU, DU and RU, introduces new opportunities for optimisation but also presents challenges in terms of energy efficiency.

Nevertheless, the increase in data demands has significantly increased the power consumption of the next-generation networks, with an estimated 75% RAN contributions [4]. Such an increase in power demands of the RAN infrastructure has prompted significant research efforts in both academia and industry to develop energy-efficient solutions [5–7]. To address these challenges, the O-RAN Alliance has proposed several energy-saving techniques, including dynamic radio resource management, intelligent sleep modes, radio chain switch-off and AI-driven power optimization [8]. Moreover, several researchers proposed algorithms to reduce the RAN power consumption by placing RUs into sleep mode as in [9, 10] or machine learning based algorithms [11, 12]. These methods aim to reduce the energy footprint of O-RAN networks by dynamically adapting power consumption to traffic demands while maintaining Quality of Service (QoS).

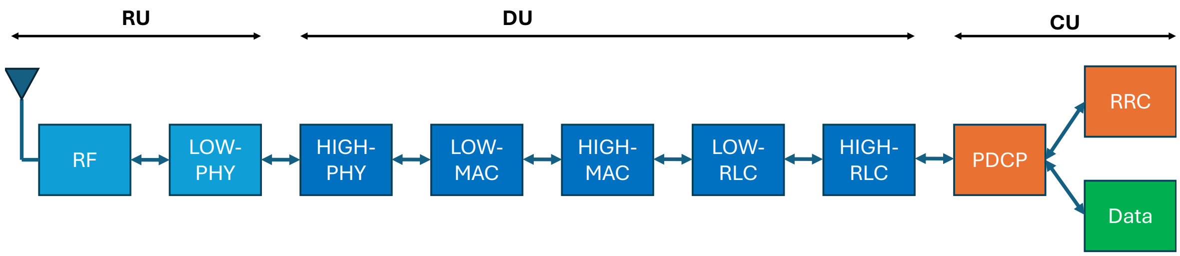
Considering these recommendations, several models have been proposed in the literature to profile RAN power consumption, such as those presented in [13] and [14]. However, these models are designed for traditional RAN architectures rather than O-RAN specific deployments. In the context of Open RAN power consumption measurements, only a limited number of studies have conducted real-world evaluations. For instance, in [15], the power consumption of cloudified and virtualised network functions was assessed using various measurement techniques. Similarly, in [16], the authors focused on CPU-level power consumption in virtualised RAN environments. In contrast, the study in [17] conducted power consumption measurements for RU and DU in an Open RAN-based LTE system; however, it was limited to the uplink case and did not specify the functional split type.

This paper presents an experimental study on power consumption in O-RAN functional splits, specifically Split 8 and Split 7.2b, under varying PRB utilisations. The Split 8 testbed is implemented using a Software Defined Radio (SDR) USRP as the RU, along with an srsRAN-based [18] DU and CU. In contrast, the Split 7.2b testbed utilises commercial RUs from Benetel [19], designed for both indoor and outdoor deployments, providing a real-world evaluation of power consumption trends. To the best of the authors'

*These authors contributed equally to this work.



(a) Split 8



(b) Split 7.2b

Fig. 1: Illustration of functional splits. (a) Split 8, (b) Split 7.2b.

knowledge, this is the first study to conduct detailed power measurements for O-RAN functional splits and for both uplink and downlink, offering empirical insights into the energy efficiency of disaggregated RAN architectures. Furthermore, the measurements obtained in this study provide foundations for developing accurate digital twins of O-RAN deployments. By employing these measurements, a digital twin model can provide a better replica to real-world scenarios, enabling a more effective power optimisation strategies for energy efficient O-RAN management.

II. O-RAN FUNCTIONAL SPLITS

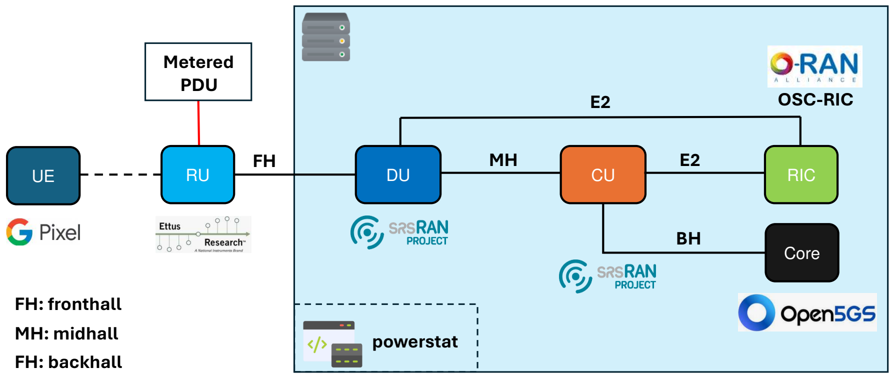
Open RAN introduces flexibility and interoperability in mobile networks through the disaggregation of traditional RAN into distinct components (i.e., RU, DU and CU) and therefore allows multiple functional split options. These splits impact latency, power consumption, fronthaul requirements and network flexibility [20]. Hence, such a modular approach is essential for an optimised deployment strategy tailored to specific network requirements. Among the various options, Split 8 and Split 7.2 with its variants have gained significant attention due to their distinct characteristics and deployment trade-offs [21].

Split 8 is shown in Fig. 1(a), represents a separation between the Physical layer (PHY) and the Radio Frequency (RF) processing to maximise virtualisation gains [22]. The RU handles only the RF signal transmission and reception. While the DU performs the baseband processing and the CU is responsible for handling higher-layer protocols . This type of deployment enables use cases that require non-standard PHY signal processing such as the cell-free MIMO networks [23].

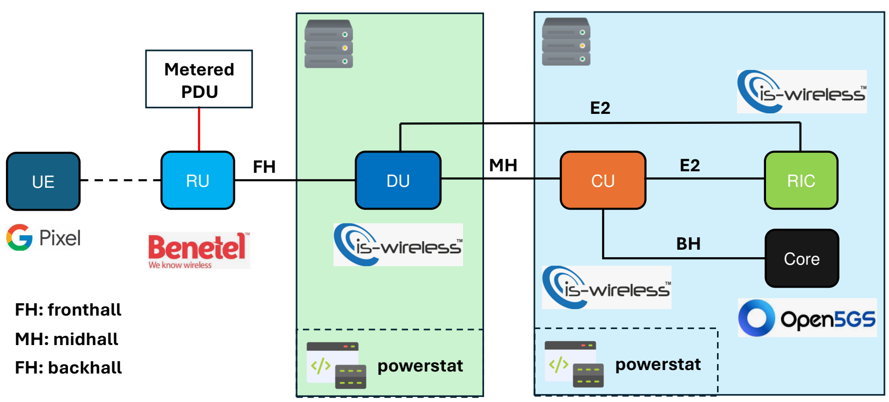
Split 7.2b on the other hand, is illustrated in 1(b), represents lower PHY layer division, specifically separating the Low-PHY and High-PHY functions. The RU handles the Low-PHY functions, such as IFFT / FFT and beamforming tasks. While the DU is responsible for High-PHY functions, including coding/decoding and modulation/demodulation processes. While the CU is responsible for the higher-layer protocol handling. Such type of deployment is suitable for use cases such as massive MIMO and Ultra-Reliable Low-Latency Communication (URLLC).

III. MEASUREMENT TESTBEDS

In this section, we describe the experimental setup used to measure the power consumption of the O-RAN. The architecture of these testbeds is depicted in Fig. 2. The server hosting the Split 8 system is a Dell PowerEdge R7515 (AMD EPYC 7662 2 GHz, 64 cores). The Split 7.2b system is hosted on two identical PowerEdge R760XA servers (Intel Xeon Gold 5420+ 2 GHz, 56 cores) with one server hosting the DU and the other hosting the other components. The power measurements for the RUs, were conducted by querying a metered Power Distribution Unit (PDU). While the power measurements for the bare metal servers with a docker image of CU, DU, RAN Intelligent Controller (RIC) and Core network utilising powerstat which is an open-source energy monitoring functionality for machines (based on intel RAPL) and estimate the power consumed based on a power consumption model [24]. In both



(a) Split 8 physical deployment



(b) Split 7.2b physical deployment

Fig. 2: The physical deployments for different functional splits: (a) Split 8 and (b) Split 7.2b.

of the measurements campaigns, the RIC was deployed but without any active xApps.

A. Split 8

The Split 8 O-RAN testbed is configured to operate with a 40 MHz bandwidth in the n78 band. The carrier frequency was set to 3.7 GHz. The testbed was designed to evaluate power consumption and performance across different O-RAN components, including the RU, DU and DU, as illustrated in Fig. 2(a), which depicts the various components:

- RU: The testbed employed a USRP, responsible for RF transmission and reception. The RU connects to the DU via a fibre fronthaul (FH).
- DU: The srsRAN DU was deployed to manage low-MAC and PHY processing, interfacing with the RU via FH.
- CU: The srsRAN CU was responsible for higher-layer RRC and PDCP processing, connected via Midhaul (MH) to the DU and Backhaul (BH) to the Core Network. The CU also interfaces with the RIC via the E2 interface.
- RIC: The FlexRIC platform was deployed to enable policy control, energy efficiency optimisation and real-time monitoring. It communicates with the CU/DU over E2 interfaces.
- Core Network: The testbed employed Open5GS, handling authentication, session management and mobility control.

The system was configured with a 6DS3U TDD pattern, allocating six slots for downlink (DL), three for uplink (UL) and one special slot for guard period or switching. The maximum Modulation and Coding Scheme (MCS) was configured to MCS 28 (64-QAM) for both uplink and downlink. A 2×2 MIMO configuration was deployed, utilising two transmit antennas (TX) and two receive antennas (RX) to improve spectral efficiency.

The maximum throughput achieved was 187 Mbps in the downlink and 42 Mbps in the uplink with MCS 28. The power consumption measurements obtained from the O-RU, O-DU and O-CU provide valuable insights into how power scales under different PRB utilisation levels, contributing to a better understanding of Split 8 energy efficiency in real-world deployments.

The testbed configurations are summarised in Table I.

TABLE I: Split 8 testbed deployment main features

Feature	Description
Frequency band	n78 (FR1, TDD)
Carrier frequency	3.7 GHz
Gain	30 dB
Bandwidth	40 MHz
Subcarrier spacing	30 KHz
TDD config	6DS3U
Number of antennas used	2 TX, 2 RX
MIMO config	2 layers DL, 1 layer UL
Maximum MCS	28 (i.e., 64-QAM)
Max throughput uplink	42 Mbps
Max throughput downlink	187 Mbps

TABLE II: Split 7.2b testbed deployment main features

Feature	Description
Frequency band	n78/n77 (FR1, TDD)
Carrier frequency	3747.8 MHz for indoor 3947.85 MHz for outdoor
Gain	24 dB
Bandwidth	40 MHz
Subcarrier spacing	30 KHz
TDD config	7DS2U
Number of antennas used	2 TX, 2 RX
MIMO config	2 layers DL, 1 layer UL
Maximum MCS	28 (i.e., 64-QAM)
Max throughput uplink	26 Mbps
Max throughput downlink	177 Mbps

B. *Split 7.2x*

The 7.2b split O-RAN testbed is configured to operate with a 40 MHz bandwidth in the n78 and n77 bands. The carrier frequency was set to 3747.8 MHz (n78) for indoor testing and 3947.85 MHz (n77) for outdoor deployment. The testbed was designed to evaluate power consumption and performance across different O-RAN components, including the RU, DU and CU as illustrated in Fig. 2(b) which depicts the various components:

- User Equipment (UE): A Google Pixel 5G device was used.
- RUs: A Benetel RAN550 and a RAN650 were employed to handle the RF transmission and reception for indoor and outdoor setups, receptively. The RU connects to the DU via a fibre FH.
- DU: The IS-Wireless DU was deployed to manage low-level MAC and PHY processing, interfacing with the RU over FH.
- CU: The IS-Wireless CU was responsible for higher-layer RRC and PDCP processing, connected via MH to the DU and BH to the Core Network. The CU also interfaces with the RIC via the E2 interface.
- RIC: The IS-Wireless RIC was deployed to enable policy control, energy efficiency optimisation and real-time monitoring. It communicates with the CU/DU over E2 interfaces.
- Core Network: The testbed employed Open5GS, handling authentication, session management and mobility control.

The system was configured with a 7DS2U TDD pattern. The maximum MCS was configured to 64-QAM for downlink and uplink. A 2×2 MIMO configuration was deployed, utilising two TX antennas and two RX antennas. The testbed configurations are summarised in Table II.

IV. Experimental measurements

In this section, we present the measurement results from the O-RAN testbeds. Subsection IV-A introduces the measurements for split 8 with USRP serving as the RU and srsRAN CU and DU. Subsection IV-B introduces the measurements for split 7.2 (split 7.2b specifically which is a variation of split 7.2) including two commercial RUs for indoor and outdoor with commercial CU and DU. We conducted the experiments inside the Institute for Safe Autonomy at the University of York. The lab is a 100 m^2 indoor lab and the UE device was placed within 3 m of the RU for better signal quality.

A. *Split 8 measurements*

Table III shows the power consumption of the uplink and downlink transmissions, respectively across different PRB utilisation levels. The uplink power consumption remains relatively stable, ranging between 43.1 W and 44.2 W, with minimal variations in the standard deviation (STD). Notably, there is no clear linear correlation between PRB utilisation and uplink power consumption, while the downlink shows a marginal increase. Such results are expected given that minimal signal processing occurs in the split 8 RU as defined by the O-RAN Alliance. Please note that 0% PRB utilisation refers to zero throughput (i.e., zero UEs attached). Therefore, we have the same uplink and downlink values.

Next, Table IV presents the combined power consumption of the CU and DU for split 8. Idle refers to having the server running alone without deploying the CU and DU (i.e., only Linux background process). The 0% PRB utilisation refers to the case that no UEs are attached to the network. In Table IV, at idle, the system consumes 58.34 W and the energy consumption was doubled when the CU and DU were switched on but not serving any UEs, indicating a significant base power requirement to have the network operating. Furthermore, as the PRB utilisation increases, both uplink and downlink power consumption increases steadily. With downlink requiring more power compared to uplink with an almost 15 W difference when in full load (i.e., PRB utilisation 100%).

B. *Split 7.2b measurements*

This subsection will introduce split 7.2b measurement results for both indoor and outdoor RUs, in addition to the CU and DU. Table V shows the measurements for the Benetel RAN550, a commercial indoor RU and Benetel RAN650 a commercial outdoor RU.

TABLE III: Power consumption of a split 8 RU under varying PRB utilisation

PRB utilisation in percentages	Uplink in Watts		Downlink in Watts	
	Mean	STD	Mean	STD
0	43.9	2.4	43.9	2.4
25	43.3	3.0	44.9	0.6
50	44.2	3.4	44.8	1.1
75	43.1	2.7	44.8	1.2
100	44.2	2.4	45.0	1.5

TABLE IV: Power consumption of split 8 CU and DU across different PRB utilisation levels.

PRB utilisation in percentages	Uplink in Watts		Downlink in Watts	
	Mean	STD	Mean	STD
Idle	58.34	4.7	58.34	4.7
0	119.51	4.02	119.51	4.02
25	120.65	3.8	123.48	4.2
50	121.21	3.93	125.37	4.14
75	124.7	3.62	128.62	4.83
100	125.19	4.05	141.59	4.57

For the Benetel RAN550, the uplink power remains nearly constant at 29.0 W, while the downlink increases slightly to 30.1 W at full PRB utlisation. Similarly, for the Benetel RAN650, the uplink power remains at 46.0 W, while the downlink rises marginally to 46.2 W at 100% PRB utilisation. Compared to Split 8, the power consumption in Split 7.2b is more stable, with minimal variations across different loads, which is expected due to using SDR as RU for split 8 configuration.

Tables VI and VII present the power consumption of the CU and DU in split 7.2 across different PRB utilisation levels. In the DU (Table VI), the power consumption starts at 187.2 W in idle mode and increases gradually with PRB utilisation, reaching 193.15 W (uplink) and 194.21 W (downlink) at full load. The power variance remains low, indicating stable performance. Similarly, in the CU (Table VII), power consumption starts at 189.6 W when idle and increases slightly to 190.97 W (uplink) and 192.67 W (downlink) at maximum PRB utilisation. The CU's power consumption is relatively stable, with minimal variation across different PRB levels. It should be noted that the power increase for both CU and DU is minimal, with variations remaining within a range of 6 W across all PRB utilisation levels.

TABLE V: Power consumption for split 7.2b RUs under varying PRB utilisation

PRB utilisation in percentages	Benetel 550 power consumption in Watts		Benetel 650 power consumption in Watts	
	Uplink	Downlink	Uplink	Downlink
0	28.3	28.3	44.6	44.6
25	29.0	29.0	46.0	46.1
50	29.0	30.0	46.0	46.1
75	29.0	30.1	46.0	46.1
100	29.0	30.1	46.0	46.2

TABLE VI: Power consumption of split 7.2b DU under varying PRB utilisation

PRB utilisation in percentages	Uplink in Watts		Downlink in Watts	
	Mean	STD	Mean	STD
Idle	187.2	0.13	187.2	0.13
0	191.8	0.42	191.8	0.42
25	191.9	0.47	192.6	0.44
50	192.6	0.48	192.8	0.43
75	193.1	0.46	193.7	0.42
100	193.2	0.62	194.2	0.39

TABLE VII: Power consumption of split 7.2b CU under varying PRB utilisation

PRB utilisation in percentages	Uplink in Watts		Downlink in Watts	
	Mean	STD	Mean	STD
Idle	189.6	0.19	189.6	0.19
0	189.8	0.29	189.8	0.29
25	189.8	0.24	190.6	0.31
50	189.9	0.26	191.5	0.28
75	190.1	0.27	192.0	0.36
100	191.0	0.3	192.7	0.36

V. Modelling the Power Consumption in Open RAN

After obtaining the measured power consumption data, we can now model it effectively. The power consumption results for the split 7.2b RAN and split's RU were consistent, as presented in Section IV. Therefore, we focus on split 8 combined DU and CU power consumptions. The quadratic polynomial fits are given as:

$$P_{UL}^{DU\&CU} = 1.86l^2 + 4.3l + 61.06 \tag{1}$$

$$P_{DL}^{DU\&CU} = 22.12l^2 - 2.4l + 62.28 \tag{2}$$

where l represents the PRB utilisation percentage. The terms $P_{UL}^{DU\&CU}$ and $P_{DL}^{DU\&CU}$ denote the power consumption for the combined DU and CU in the uplink and downlink, respectively. Fig. 3 illustrates the measured power consumption alongside the quadratic model fit. As observed, the downlink exhibits higher power consumption than the uplink, which aligns with expectations due to increased transmission demands in the downlink in terms of throughput.

VI. Conclusions

In this work, a comprehensive measurements and analysis of power consumption in O-RAN functional splits, focusing on Split 8 and Split 7.2b. The empirical results showed that the power consumption in O-RAN components, including RUs, DUs and CUs, does not scale proportionally with PRB utilisation and a significant portion of energy consumption remains constant regardless of network load. This highlights the need for energy-efficient strategies in O-RAN deployments to focus on switching on/off radio chain or RAN components. In addition, the results showed that downlink power consumption is consistently higher than uplink, which aligns with the

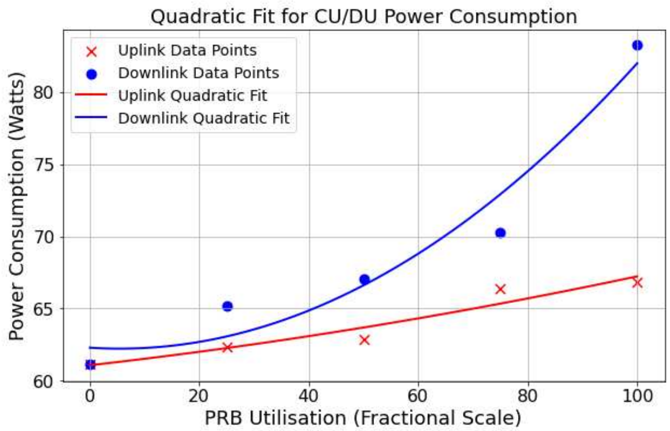


Fig. 3: Comparison between measured and quadratic fit power model for split 8 DU and CU.

increased processing and transmission demands in throughput for downlink.

The empirical measurements obtained in this study not only aid in developing energy-saving solutions but also contribute to the creation of a digital twin for the network. By leveraging these insights, advanced power-saving mechanisms such as intelligent resource management, dynamic power adaptation, AI-driven optimization techniques, and digital twin-based energy modelling can be effectively implemented. Digital twin technology, in particular, plays a crucial role in real-time network monitoring, power forecasting, and proactive energy management, enabling operators to simulate different configurations and dynamically optimize power consumption. These solutions collectively help mitigate the energy footprint of O-RAN deployments while ensuring network performance and service quality.

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