AI/ML for Beam Management in 5G-Advanced using PPO with OAI, FLEXRIC and RFSIM

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***Abstract*—Beam management (BM) is pivotal in 5G and future networks for maintaining high-throughput links, especially in mmWave bands. This work implements a reinforcement learning (RL)-based BM solution using Proximal Policy Optimization (PPO) integrated with OpenAirInterface (OAI), FLEXRIC, and RFSIM. The proposed system aligns with ongoing standardization efforts in 5G-Advanced for AI-native interfaces. We detail the system architecture and contextualize it with industrial insights from recent standardization literature.**

***Index Terms*—Beam Management, PPO, OpenAirInterface, FLEXRIC, RFSIM, Reinforcement Learning, E2 Agent, AI/ML, 5G-Advanced**

I. Introduction

Beam management (BM) in 5G is critical for ensuring link reliability under high-frequency and high-mobility conditions. Traditional methods suffer from high latency and overhead. The integration of AI/ML—particularly reinforcement learning—has been proposed in 5G-Advanced to enhance BM accuracy, reduce latency, and minimize signaling overhead [1]. This work demonstrates a working prototype using PPO, interfacing with a simulated RAN stack and aligning with O-RAN's E2 interface design.

II. Architecture Overview

A. Reinforcement Learning Agent (PPO)

The PPO agent is designed in Python using Stable-Baselines3. It receives state inputs such as RSRP and SINR via FLEXRIC and outputs beam IDs, power levels, or MCS selections. It interacts with FLEXRIC via REST or gRPC, executing a standard RL loop: Observe $\rightarrow$ Act $\rightarrow$ Reward $\rightarrow$ Update.

B. OpenAirInterface (OAI)

gNB: Uses the nr-softmodem with E2 Agent enabled. Receives beam commands, sends KPM reports.
UE: Simulated using nr-uesoftmodem. Communicates with gNB via RFSIM.
Supports multiple configurations (.conf), including NSA/SA and PHY-MAC stack.

C. RF Simulator (RFSIM)

Simulates RF links over localhost. Operates with TCP-based interfaces and supports channel models (AWGN). Enables full-stack simulation without hardware.

D. FLEXRIC

Implements the E2 Termination and xApp Manager. Supports KPM and RC service models. Used to extract metrics and apply beam control actions. Communicates over SCTP and REST/gRPC.

E. xApp and Interface

Acts as middleware between the PPO agent and FLEXRIC. It parses E2SM-KPM messages and issues E2SM-RC control commands based on PPO decisions.

F. OAI E2 Agent Plugin

Integrated with gNB. Transmits KPM data (e.g., CQI, SINR) and receives RC control actions for beam control.

G. Optional Logging/Buffer

Uses Redis or SQLite to buffer training data or log decisions for offline learning/debugging.

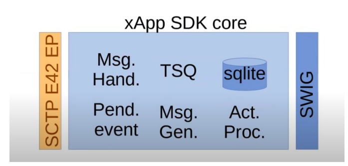

Fig. 1. System Architecture

III. Installation Overview

The installation process for enabling E2AP and E2SM functionalities in OAI is outlined as follows:

- Ensure dependencies are installed: including ASN.1 compilers, protobuf, and gRPC libraries.
- Clone the OAI repository and switch to the 'develop' branch.
- Build the E2 Agent using:

```
cd openairinterface5g
source oaienv
cd cmake_targets
./build_oai -I --gNB --nrUE --e2agent
```

- Configuration files are found under 'targets/PROJECTS/GENERIC-NR-5GC/CONF'.
- To run with E2AP support, launch the gNB using:

```
sudo -E ./nr-softmodem -O gnb.conf --
    rfsim --E2ap.enable
```

- Metrics and control commands will be managed via E2SM-KPM and E2SM-RC messages.

We can refer to the full installation guide at: https://gitlab.eurecom.fr/oai/openairinterface5g/-/blob/develop/openair2/E2AP/README.md

IV. Industrial Context and Standards

As detailed in [1], 5G-Advanced standardization promotes AI-native beam management. Spatial Beam Prediction (SBP) and Temporal Beam Prediction (TBP) are two AI-ML frameworks being evaluated. Our system reflects a gNB-side SBP with PPO-based inference, aligning with key findings:

- SBP using AI yields higher accuracy (e.g., up to 63.5% in Qualcomm evaluations).
- TBP extends beam estimation temporally, useful for proactive link adaptation.
- E2AP and xApp-based interfaces conform to modular and scalable designs expected in RIC architecture.

Our prototype adheres to these design goals, demonstrating a real-world instantiation of the proposed frameworks.

V. Data Flow Summary

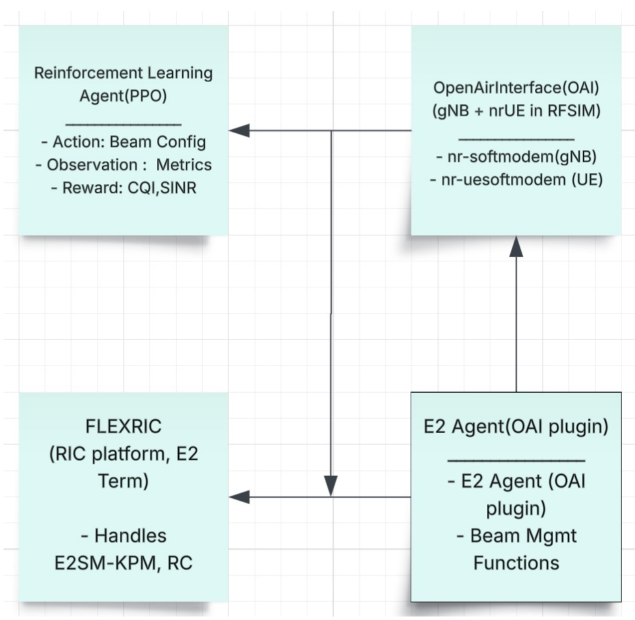

Fig. 2. Architectural Representation Diagram for Dataflow

The data flow in our architecture follows a structured pipeline beginning with simulated UEs interacting with the OAI-based gNB. The gNB is equipped with an integrated E2 Agent, which communicates performance metrics such as SINR and RSRP to the near-RT RIC using the E2AP protocol. FLEXRIC serves as the RIC platform where these observations are forwarded to the PPO agent. The PPO agent processes the data and sends back control actions (like beam ID, power levels) to FLEXRIC, which are then applied at the gNB. This feedback loop facilitates learning and real-time optimization of beam configurations.

VI. Conclusion and Future Work

This paper demonstrates a working architecture that integrates PPO-based learning with OAI and FLEXRIC. Future improvements include incorporating TBP, model generalization across UE scenarios, and deploying on real RAN testbeds. Alignment with standardization ensures relevance and scalability in commercial deployments.

Resources

- OAI E2AP Readme: https://gitlab.eurecom.fr/oai/openairinterface5g/-/blob/develop/openair2/E2AP/README.md
- OAI Installation Guide: https://docs.oracle.com/cd/A87860_01/doc/win.817/a86040/toc.htm
- Build Type Document: https://gitlab.eurecom.fr/oai/openairinterface5g/-/blob/develop/doc/BUILD.md

References

[1] Q. Xue et al., ”AI/ML for Beam Management in 5G-Advanced: A Standardization Perspective,” arXiv:2309.10575v2, 2024.