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Adaptive layer splitting for wireless large language model inference in edge computing: a model-based reinforcement learning approach

Key words: Large language models (LLMs); Edge computing; Model-based reinforcement learning (MBRL); Split inference; Transformer

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Motivation

- The field of natural language processing (NLP) has recently experienced transformative changes, driven by the rapid advancement of large language models (LLMs) such as GPT-4 and Gemini. These models are highly proficient at generating human-like text, catalyzing progress across various domains. However, LLMs' substantial computational demands often exceed the processing capacities of communication-limited user equipment (UE), which makes the integration of edge computing a complementary paradigm to enhance computational efficiency and privacy.

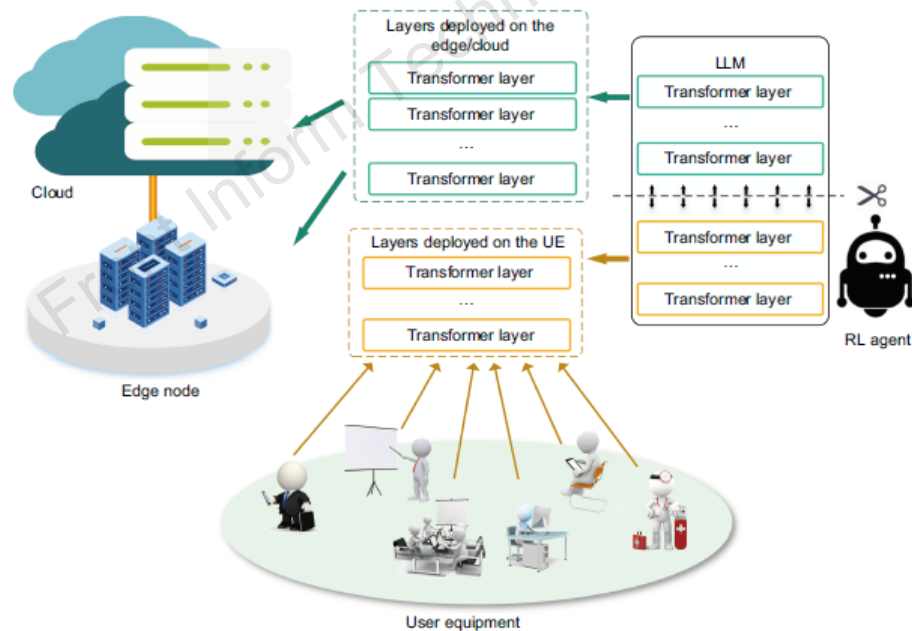


Fig. 1 A high-level architecture of the framework, depicting the distribution of the large language model (LLM) across the edge and the user equipment (UE), highlighting the role of the reinforcement learning (RL) agent in managing interactions between the LLM and wireless networks

Main idea

- To address the computational and communication challenges of deploying large language models (LLMs) in edge computing environments, this paper introduces a framework inspired by model-based reinforcement learning (MBRL). The framework focuses on determining the optimal splitting point between user equipment (UE) and edge nodes, balancing inference performance and computational load. This approach adapts to varying network conditions, minimizing the impact of unreliable wireless channels, and significantly reduces the computational cost of frequent performance evaluations.

Method

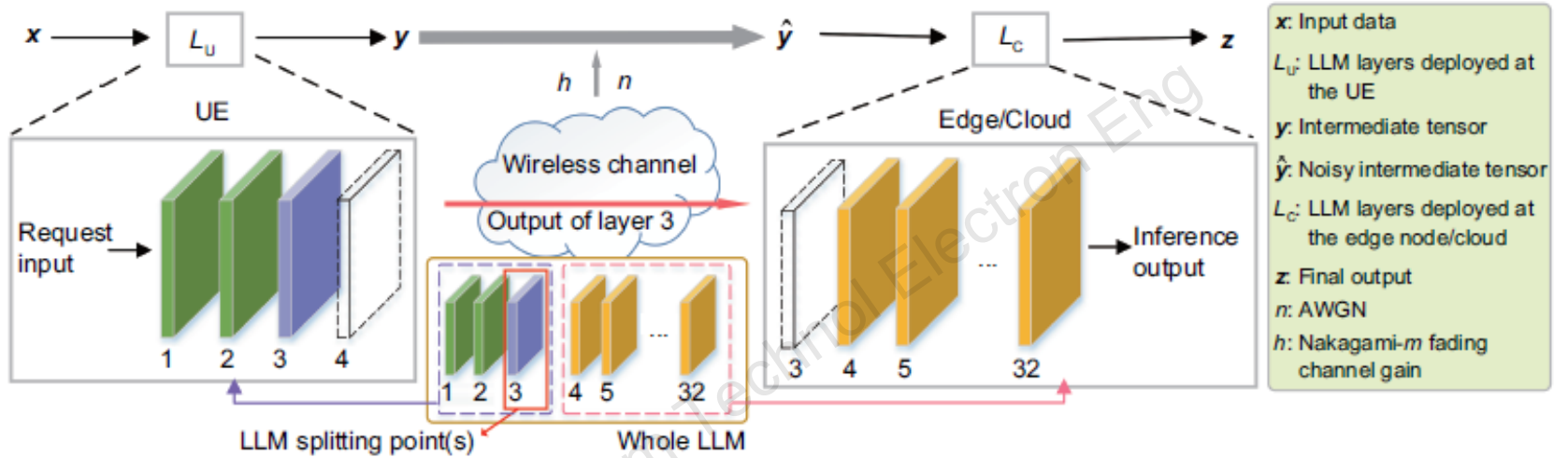


Fig. 2 Overview of the split model architecture in wireless channel, with layer 3 designated as the example splitting point. We use the 32-layer LLaMA2-7B model as an example

Optimize the splitting point p^* by minimizing the trade-off between inference performance (PPL) and computational load (C_{UE}).

$$p^* = \arg \min_p [\text{PPL}(p; \sigma, m) + \lambda \cdot C_{UE}(p)]$$

Method

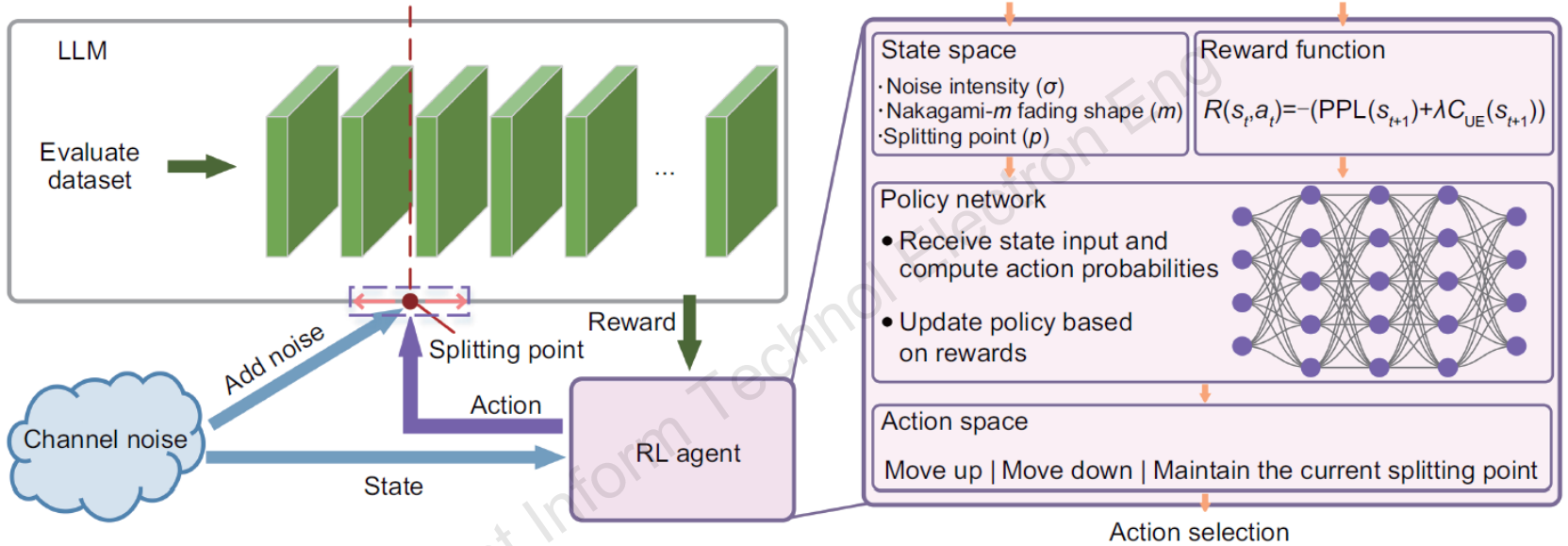


Fig. 4 Illustrations of the reinforcement learning (RL) setup, including the large language model (LLM), RL agent, and channel noise modules. The RL agent optimizes the splitting point of the LLM by receiving state inputs (noise intensity, Nakagami- m fading shape, and splitting point), computing action probabilities via the policy network, and updating the policy based on the reward function

Results

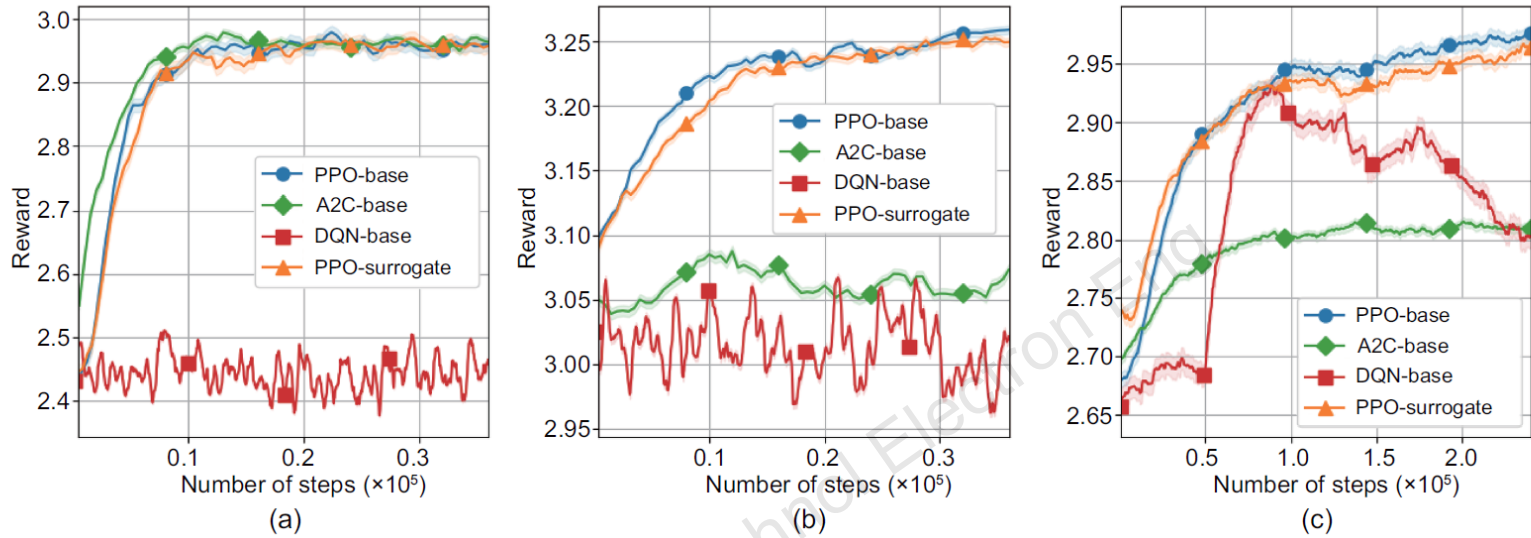


Fig. 5 Comparison of training performances for different reinforcement learning (RL) approaches under case *L* (a), case *H* (b), and case *A* (c)

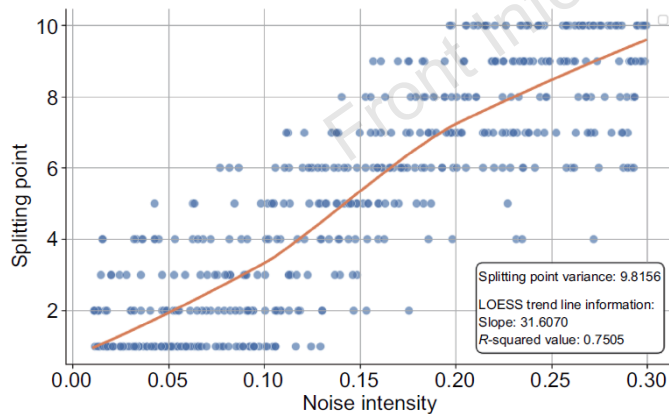


Fig. 7 Splitting points determined by the trained PPO agent across different noise intensities, along with a LOESS trend line

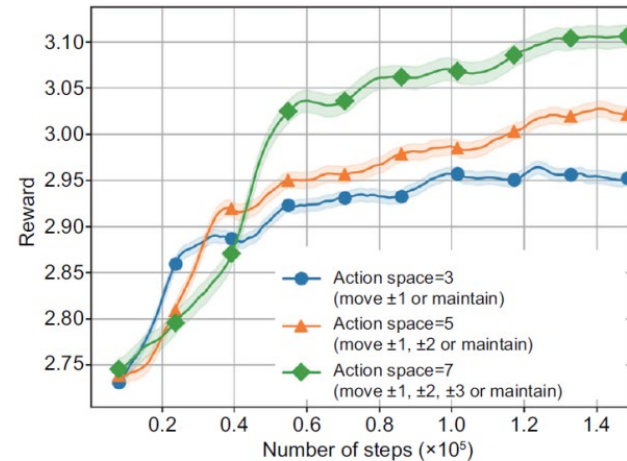


Fig. 8 Comparison of training performances across different action spaces (action space=3, 5, or 7) for varying movement ranges

Conclusions

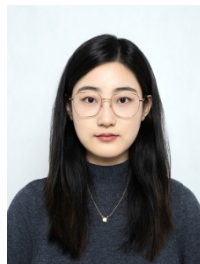
This paper presents an MBRL-based framework for dynamically optimizing the splitting point of large language models (LLMs) across edge devices and cloud resources. The proposed method effectively balances inference performance and computational load, adapting to fluctuating network conditions. Our results demonstrate that this approach offers a robust solution for deploying LLMs in decentralized environments, improving both efficiency and flexibility.



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