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Reinforcement Learning-Based End Host Path Optimization for Path-Aware Networks

1 Introduction

As Path-Aware Networking (PAN) becomes a prominent paradigm in modern Internet architecture, a growing need exists for intelligent mechanisms that can optimize end-to-end network performance. PAN allows end hosts to be aware of multiple network paths and their characteristics, enabling more adaptive and efficient communication strategies.

This project proposes to leverage Reinforcement Learning (RL) techniques to enable end hosts in PAN networks to intelligently optimize path selection and sending rates, dynamically adjusting to real-time network conditions. The primary focus is on designing an RL-based framework where end hosts make decisions at two critical levels: (1) selecting appropriate sending rates on a given path for congestion control and (2) switching to a more optimal path when available and adjusting the sending rate accordingly.

1.1 Example Use Case

Consider a video conferencing application running over a PAN network. The RL agent, embedded in the end host, continuously monitors the performance of the current path, tracking metrics such as round-trip time (RTT), packet loss, and available bandwidth. As the network conditions fluctuate—due to increased traffic or a degraded wireless connection—the agent dynamically adjusts the sending rate to prevent congestion and maintain a smooth video stream.

Simultaneously, the agent monitors alternative paths in the PAN environment. When a more reliable path with lower latency and higher available bandwidth becomes available, it switches to this new path. Upon switching, the agent recalculates the optimal sending rate based on the characteristics of the new path, all while minimizing any disruptions to the video stream.

Over time, the RL agent learns to predict network conditions and optimize its decisions proactively, improving the overall performance of the video conferencing application and maximizing the user's Quality of Experience (QoE).

2 Key Research Challenges

This project addresses several critical challenges in designing and implementing an RL-based system for PAN networks:

Metrics for Decision-Making: The RL agent will rely on real-time network metrics like latency, jitter, packet loss, bandwidth, and RTT. A key challenge is determining which metrics are most critical for optimizing path selection and sending rates, balancing throughput, delay, and stability for optimal performance. The agent must learn how to weigh these metrics appropriately.

Processing Sequential Network Data: Since network conditions evolve over time, the RL agent must be capable of processing sequential data to predict future network states. This requires the agent to identify and leverage temporal patterns in the network metrics, such as periodic congestion or bursty traffic episodes, and adjust its decisions accordingly.

Designing Reward Function: The project must design a reward function that accurately reflects the objectives of the network (e.g., maximizing QoE) while balancing factors like latency and throughput.

Dealing with Cold-Start: The cold-start problem occurs when the system lacks historical data to guide decisions, both at startup and when switching paths. Without enough experience, the RL agent may make suboptimal choices, such as selecting an inappropriate sending rate. The challenge is ensuring reasonable decisions are made without relying on extensive prior data.

3 Requirements

The applicant should have experience with C++ and Python, and be familiar with networking protocols, the ns-3 simulator, and reinforcement learning.

4 Contact

For more information or to express interest in the project, please contact:

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