QCMP: Load Balancing via In-network Reinforcement Learning

Changgang Zheng*, Benjamin Rienecker*, Noa Zilberman

E-mail: changgang.zheng@eng.ox.ac.uk

Computing Infrastructure Group, University of Oxford

SIGCOMM FIRA 2023, 10th of September

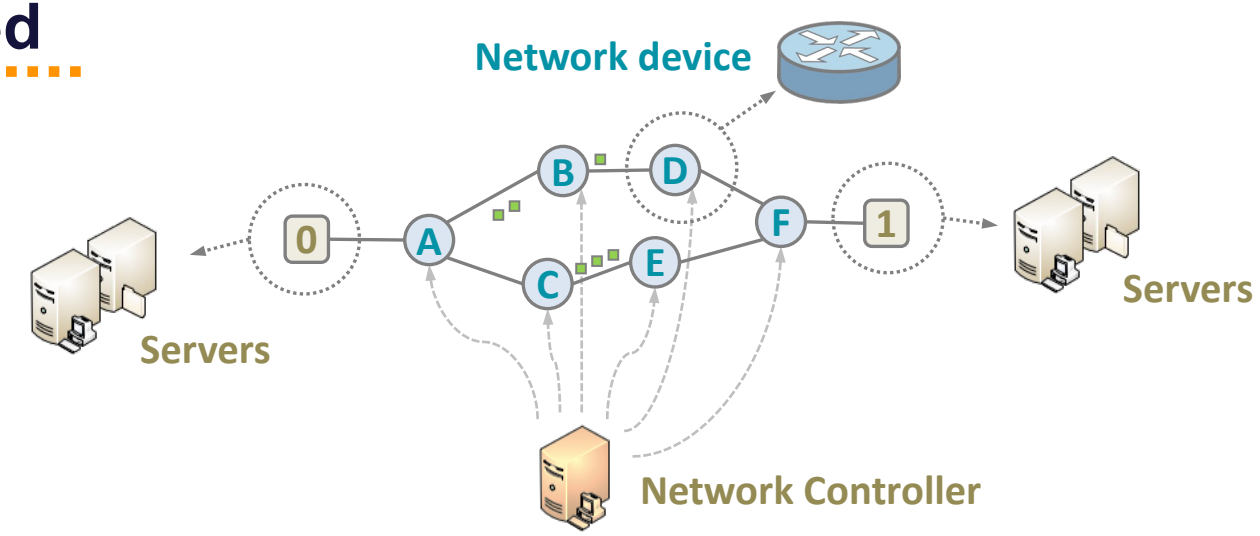
* Changgang Zheng and Benjamin Rienecker contributed equally to this work.

Background: Load Balancing

DEPARTMENT OF ENGINEERING SCIENCE
UNIVERSITY OF OXFORD

Three Common Load Balancing Solutions:

1. Centralized controller-based
2. Host-based
3. Switch-based
   - I. ECMP
   - II. CONGA
   - III. HULA



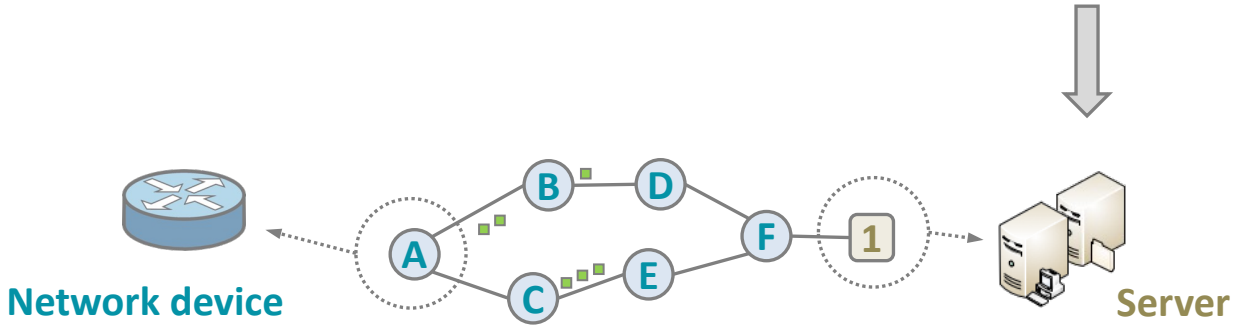
Fixed load balancing policies, unable to dynamically adapt to unknown environments.

Background: In-Network ML

In-network ML refers to offloading inference or entire ML processes to the network.

In-Network

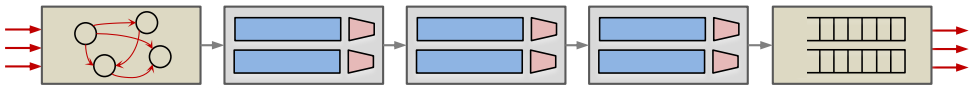
Machine Learning Decision



What Is In-Network Machine Learning?

DEPARTMENT OF ENGINEERING SCIENCE

UNIVERSITY OF OXFORD

General Machine Learning	**vs**	***In-Network Machine Learning***
Local PC, Servers, …	Location	*Network Infrastructures*
CPU, GPU, …	Device	 **PISA**
C, Python, MATLAB, …	Language	*P4*
Training & Inference	Manner	*Offline Training Online Inference*

Why In-Network Q-Learning?

DEPARTMENT OF ENGINEERING SCIENCE
UNIVERSITY OF OXFORD

Requirements:

1. Low Complexity
2. Low Latency (Offline)

Q-Learning:

1. Model-Free
2. Value-Based
3. Offline Learning

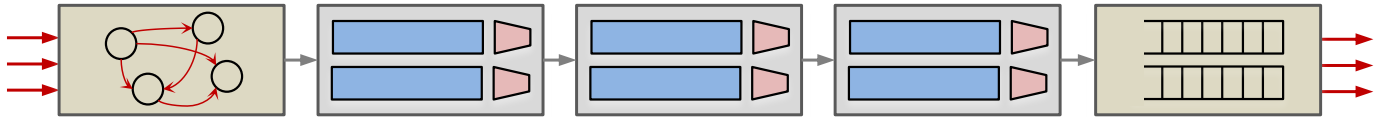
Algorithm 1: Q-learning

Initialize: $Q(s,a)$ arbitrarily

Repeat // for each episode
  Initialize s;
  Repeat // for each step of episode
    $a \leftarrow Q(,)$ and s using policy e.g., ϵ-greedy;
    Take action $a \rightarrow$ observe r and s';
    $Q(s,a) \leftarrow Q(s,a) + \alpha[r + \gamma \max_{a'} Q(s',a') - Q(s,a)]$;
    $s \leftarrow s'$;
  while *step is not terminal*;
while *episode is not terminal*;

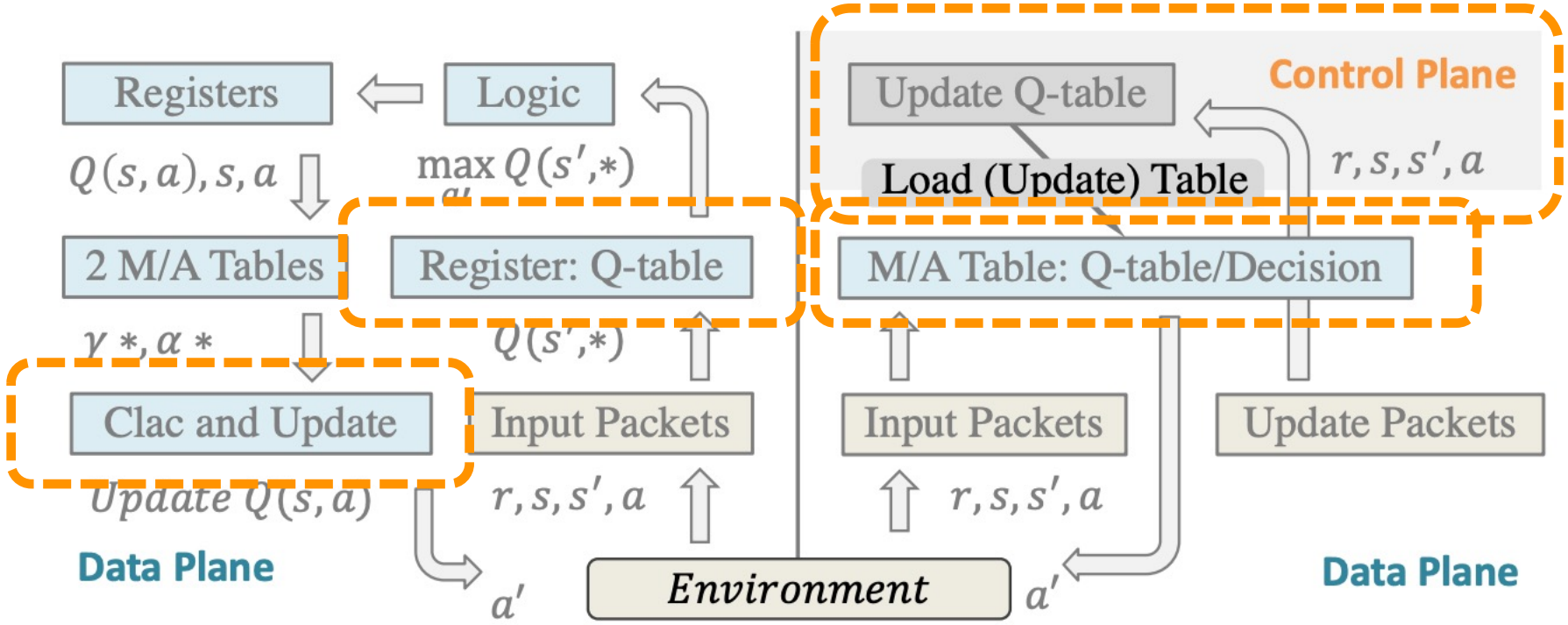
Challenges

Resources on network devices are very limited compared to PC or servers.



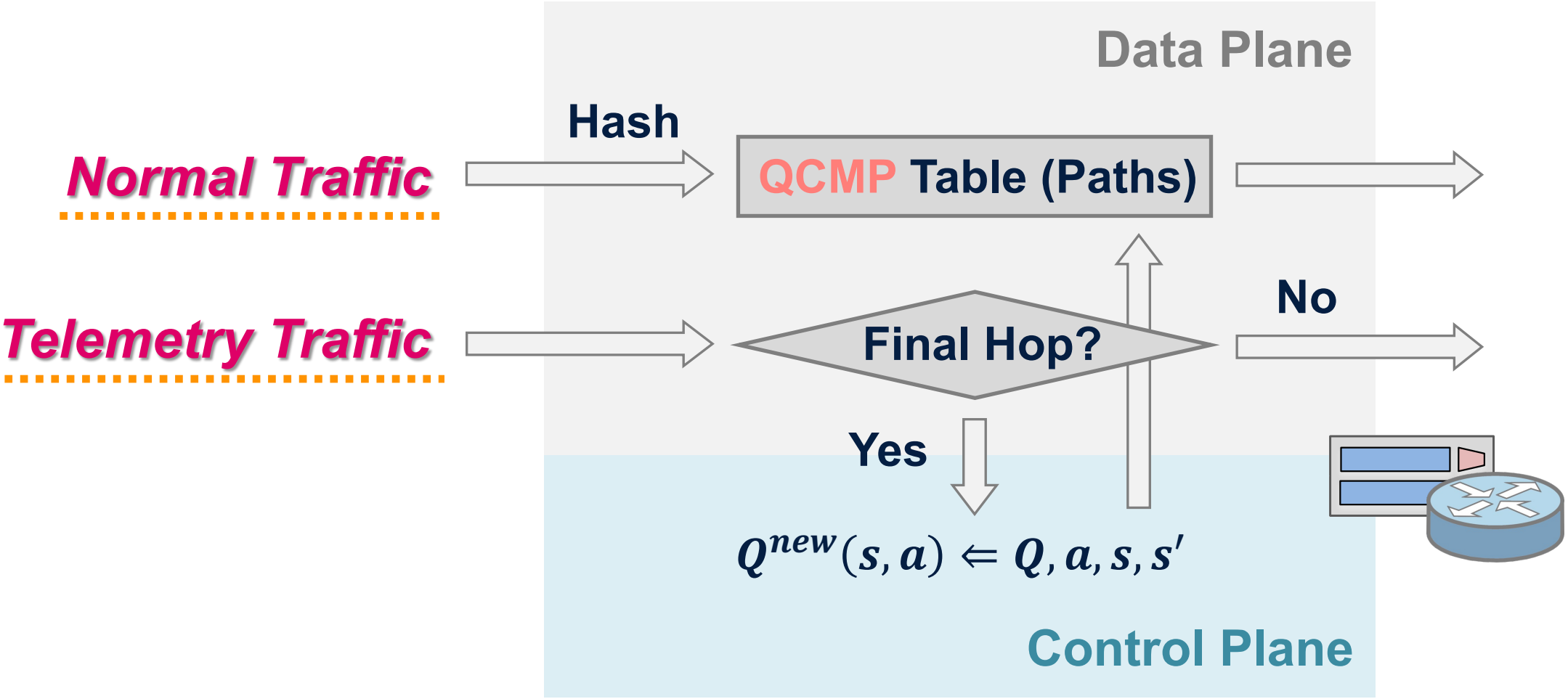
1. Limited mathematical operations
2. Limited memory
3. Limited data types
4. Limited stages

In-Network Q-Learning Solutions

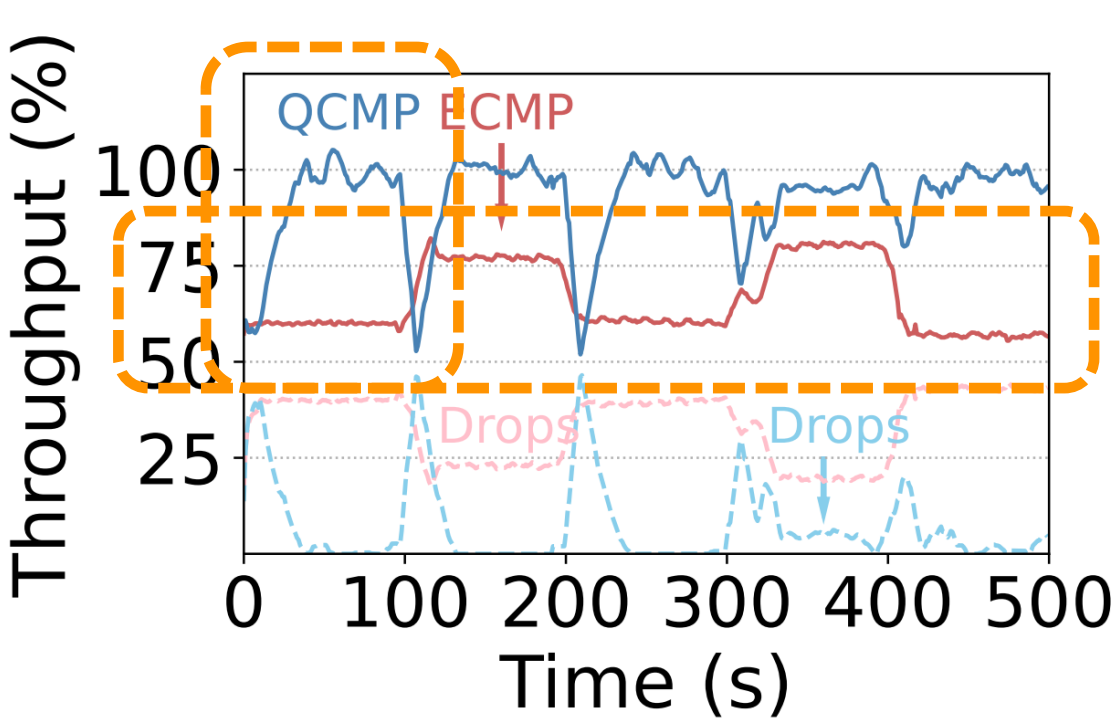


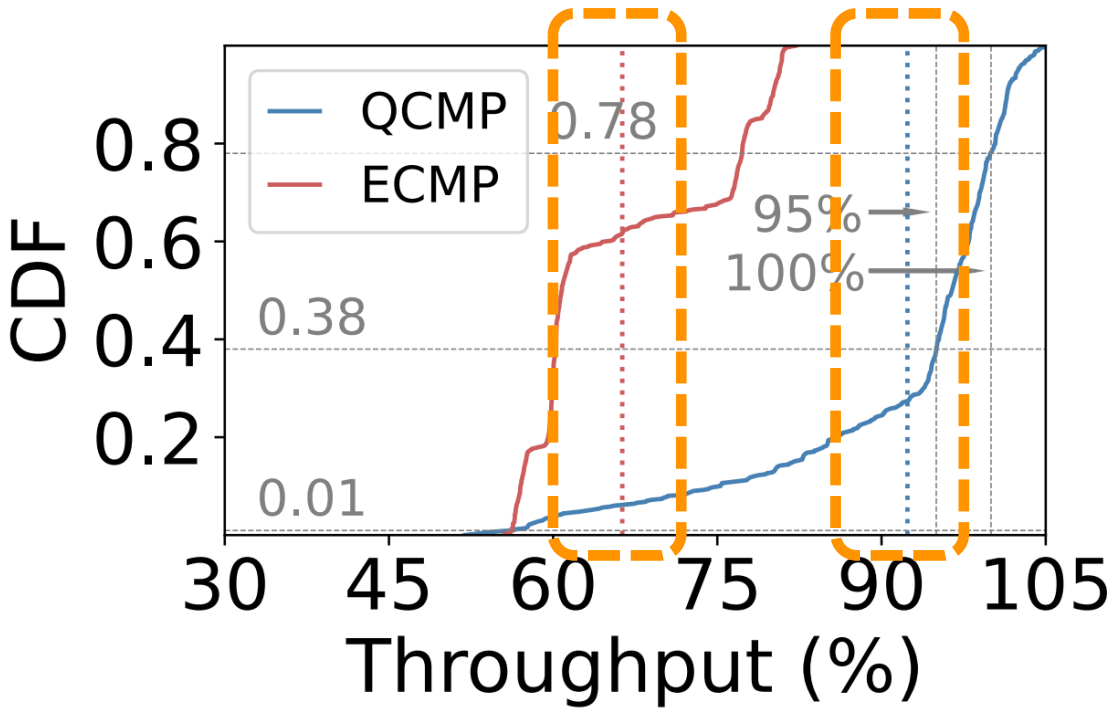
(a) Register-based Q-learning (b) M/A table-based Q-learning

Q-Learning Cost Multi-Path (QCMP)



QCMP Evaluation





Summary

Q: What is the limitation of current load balancing solutions?

A: Cannot dynamically adapt to unknown environments.

Q: How to realize in-network Q-learning?

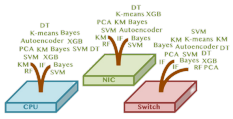
A: Introduced register-based & M/A table-based Q-learning

Q: How to solve the load balancing problem?

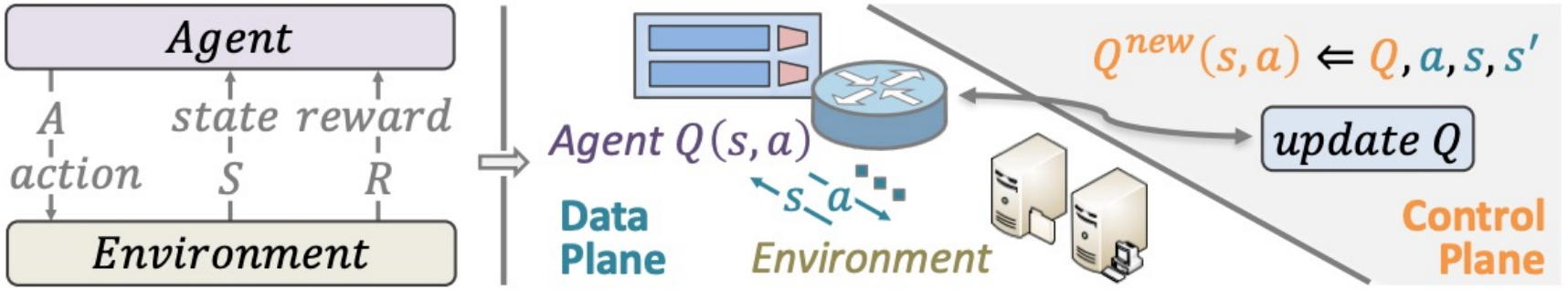
A: QCMP (with M/A table-based Q-learning).

Q: How to realize other in-network machine learning algorithms?

A: Use Planter framework:



PLANTER



QCMP: Load Balancing via In-network Reinforcement Learning

Changgang Zheng* changgang.zheng@eng.ox.ac.uk https://changgang-zheng.github.io/Home-Page

Benjamin Rienecker*

Noa Zilberman noa.zilberman@eng.ox.ac.uk https://eng.ox.ac.uk/computing

Computing Infrastructure Group, University of Oxford

SIGCOMM FIRA 2023, 10th of September

* Changgang Zheng and Benjamin Rienecker contributed equally to this work.