NetAIGym: Democratizing "Network AI" Research & Development via Simulation-as-a-Service

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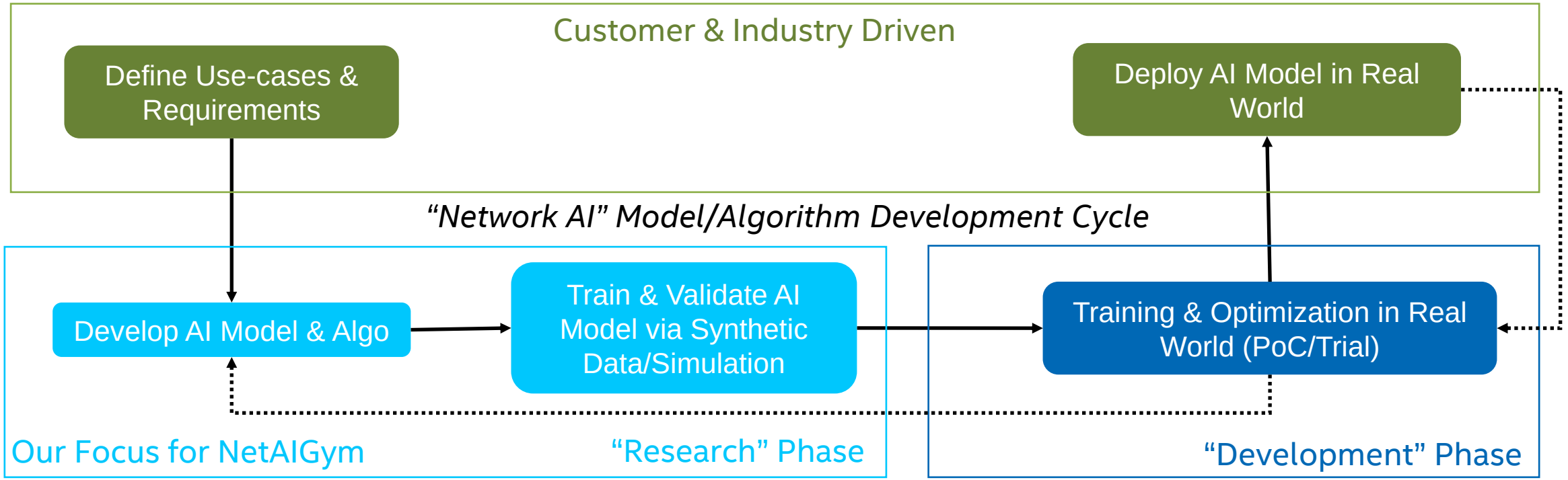
Acknowledge: Shu-ping Yeh

Motivation: Where is “Data” ?



- Network AI Developer Challenges (Why NetAIGym ?)
  - real-world dataset controlled by network operator, difficult to acquire, not aligned with specific usage or requirement
  - “dataset” by itself not enough, also need “environment” to train/test AI models, e.g. Reinforcement Learning, etc.
  - network simulation tools (e.g. ns3, etc.) often very complex and difficult to use, especially for Network AI researcher & developer

Gap: lack of common “Simulation” environment with simple “APIs” to develop, evaluate, and benchmark “Network AI” models & algos

Related Work: OpenAI Gym / Gymnasium

github.com/Farama-Foundation/Gymnasium

LICENSE	License.txt -> License (#59)	6 months ago
README.md	Update comet section readme (#437)	3 weeks ago
gymnasium-text.png	Add files via upload	6 months ago
pyproject.toml	Pin MuJoCo 2.3.3 (#463)	4 days ago
setup.py	Add back long description to setup (#243)	3 months ago

README.md

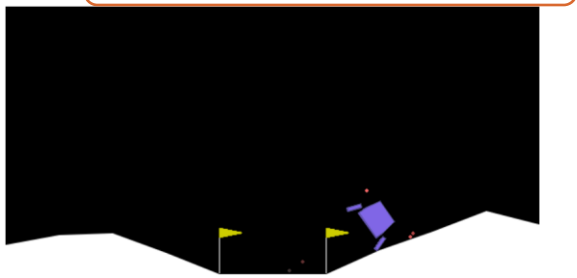
pre-commit enabled | code style black

Gymnasium

Gymnasium is an open source Python library for developing and comparing reinforcement learning algorithms by providing a standard API to communicate between learning algorithms and environments, as well as a standard set of environments compliant with that API. This is a fork of OpenAI's Gym library by it's maintainers (OpenAI handed over maintenance a few years ago to an outside team), and is where future maintenance will occur going forward.

The documentation website is at gymnasium.farama.org, and we have a public discord server (which we also use to coordinate development work) that you can join here: https://discord.gg/bnJ6kubTg6

Gymnasium is a standard API for reinforcement learning, and a diverse collection of reference environments



Gymnasium is a maintained fork of OpenAI's Gym library. The Gymnasium interface is simple, pythonic, and capable of representing general RL problems, and has a compatibility wrapper for old Gym environments:

```
import gymnasium as gym
env = gym.make("LunarLander-v2", render_mode="human")
observation, info = env.reset(seed=42)
for _ in range(1000):
   action = env.action_space.sample()  # this is where you would insert your policy
   observation, reward, terminated, truncated, info = env.step(action)

   if terminated or truncated:
      observation, info = env.reset()
env.close()
```

Source: https://gymnasium.farama.org/

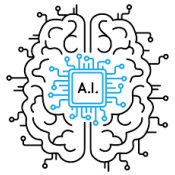
"Environment" is as important as "Data" (if not more) for Network AI R&D

NetAIGym: An Open "Network AI" Simulation-aaS Framework

Network Intelligence Controller (Algorithm)

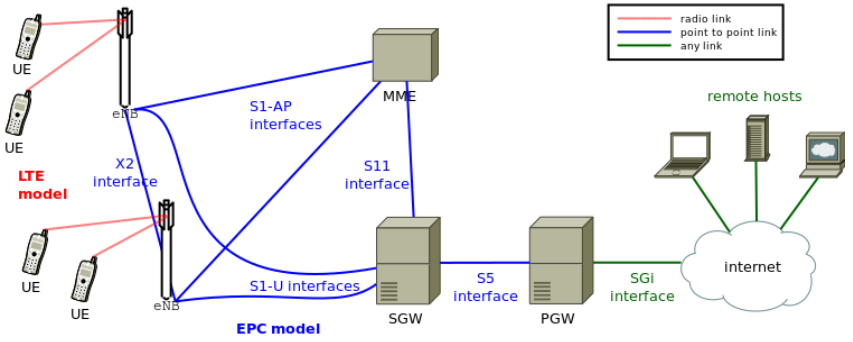
(Traffic Management, RAN slicing, Energy Saving, etc.)

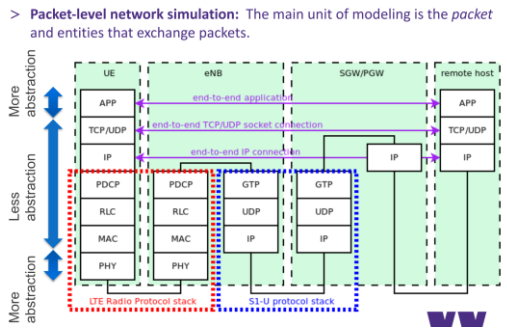
- Rule/Policy based Models/Algos
- Reference ML/AI Models/Algos
- 3rd party ML/AI Models/Algos



Configuration (use-case, topology, traffic, etc.) ↓ *Action* ↓ ↑ *Observation/Data (State, Reward)*

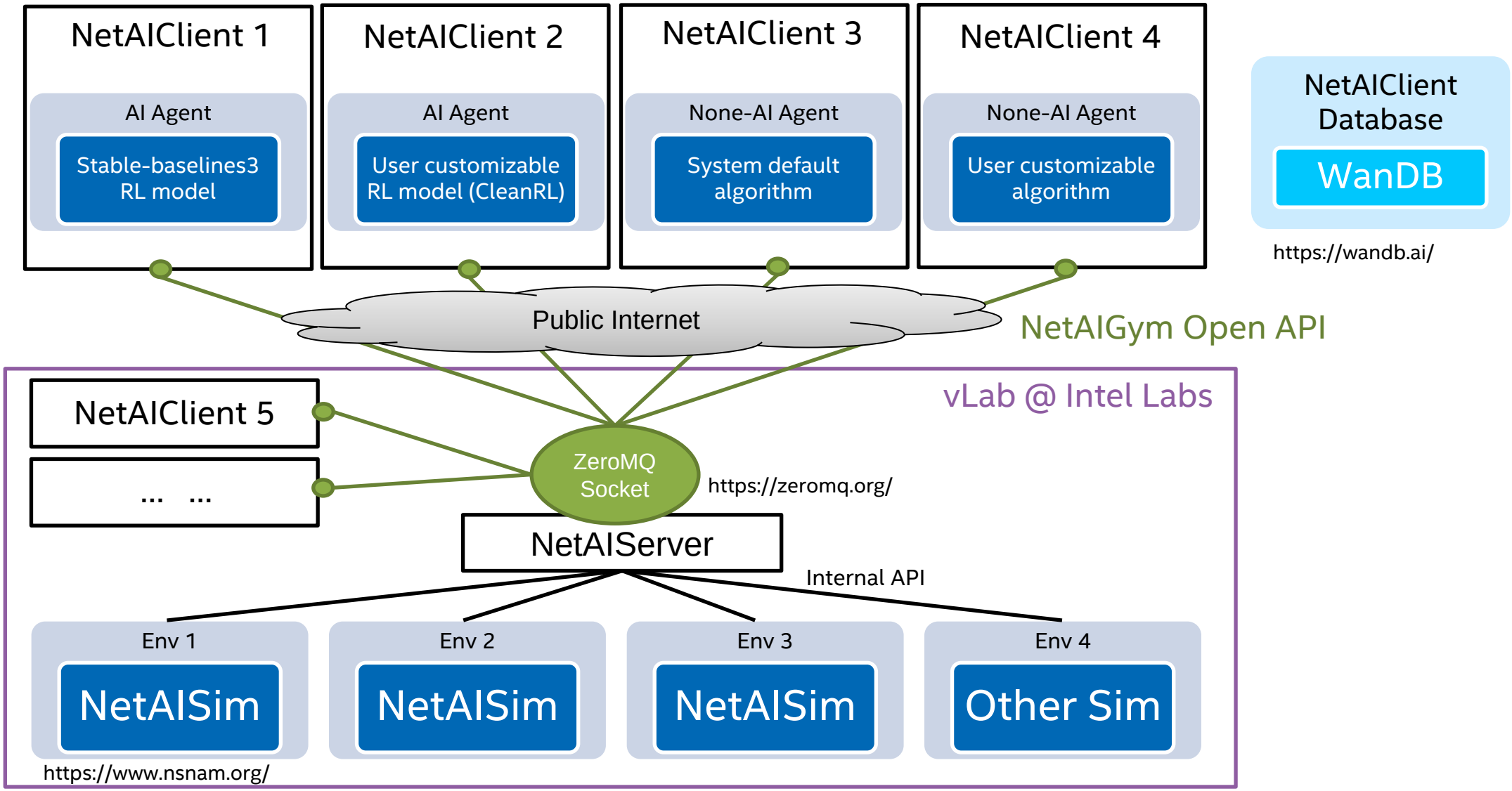
ns3-based Full-Stack e2e Network Simulator (Environment)





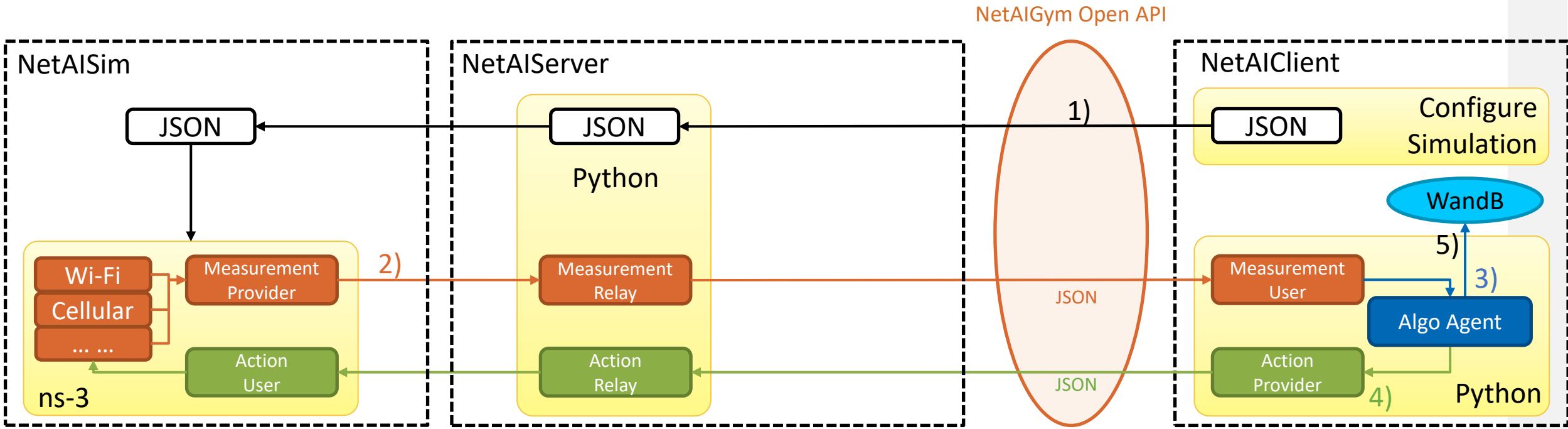
1. Open Toolkit (Library, Models, Examples, etc.) for Network AI algorithm development
   - NetAIClient
2. Open API for collecting data and interacting with the simulated network environment
   - NetAIGymAPI
3. **Open Network Simulator**
   Leverage open-source network simulation tools, e.g. ns3; Enhance it with customized capabilities & use-cases, e.g. Traffic Steering, Network Slicing, Distributed Compute, Dynamic QoS, Energy Saving, etc.
   - NetAIServer
   - NetAISim

NetAIGym PoC: “Sim-aaS” E2E Infrastructure via vLab



NetAIClient Repo: https://github.com/pinyaras/GMAClient

NetAIGym Sim-aaS E2E Workflow



1) **NetAIClient** sends a JSON configure file to **NetAIServer** to launch a ns-3 simulation.
2) **NetAISim** collects and sends measurement metrics to **NetAIServer.**
3) **Algorithm Agent** computes an action based on the measurements, and stores data in WandB.
4) **NetAIClient** transmits the action to the **NetAISim** via the **NetAIGym Open API**.
5) The measurement history can be visualized via the **Web-based WanDB**.

A List of Supported Measurement Metrics

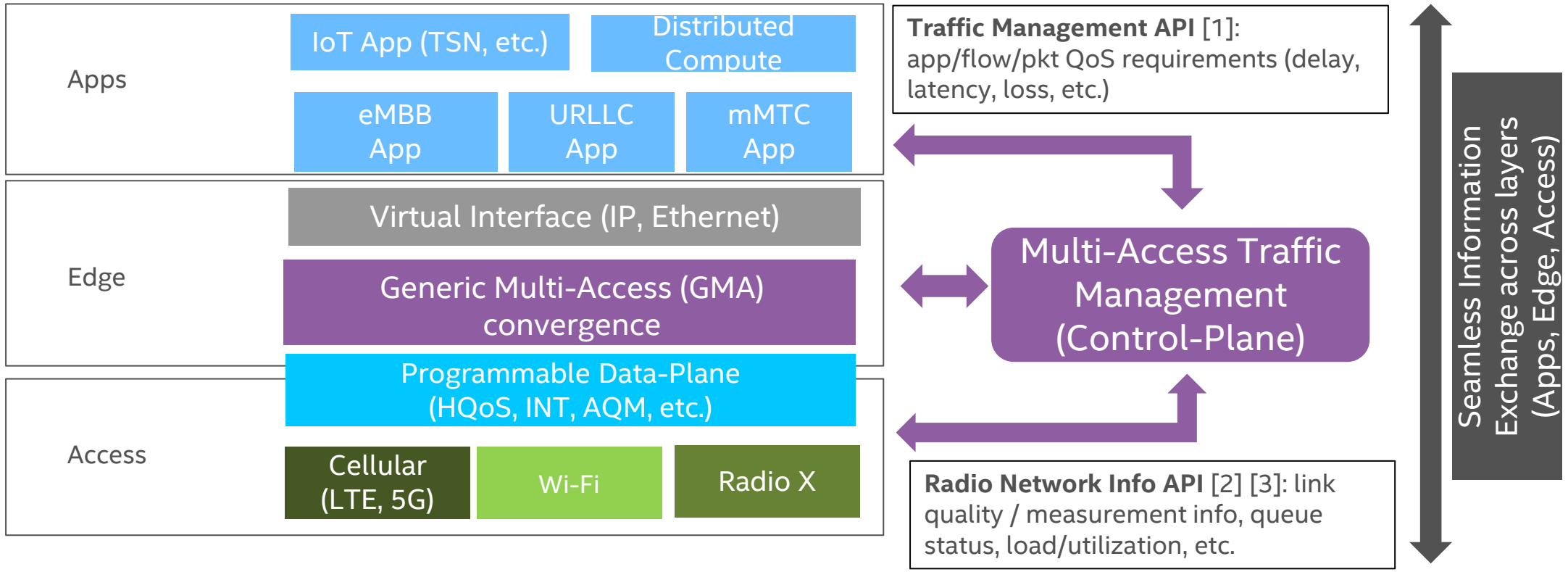
Measurement	Unit	Description
max_rate	mbps	LTE/Wi-Fi link capacity measured by each user
load	mbps	input traffic throughput measured by each user
rate	mbps	output traffic throughput measured by each user, including LTE, Wi-Fi, and ALL
qos_rate	mbps	output traffic throughput that meets the QoS requirement, including LTE, Wi-Fi, and ALL
owd	ms	one-way delay measured by each user, including LTE, Wi-Fi, and ALL
tsu		traffic split ratio measured by each user, including LTE, Wi-Fi
ap_id		access-point/cell ID measured by each user, including LTE and Wi-Fi
slice_id		(LTE) slice ID measured by each user
rb_usage	%	(LTE) resource block usage measured by each user
delay_violation	%	one-way delay violation percentage (%) measured by each user
…		

A List of Supported Use Cases and Actions

Use-Case	Action	Description
Multi-Access (MX) Traffic Splitting	Traffic Splitting	update traffic split ratio of a flow over Wi-Fi and LTE
QoS-aware MX Traffic Steering	Traffic Steering	steer traffic over Wi-Fi or LTE for a flow
Cellular RAN Slicing	Resource Allocation	update LTE resource block allocation ratio for a slice
…		

NetAIGym Example: Multi-Access (MX) Traffic Splitting

Multi-Access Virtualization Framework: GMA

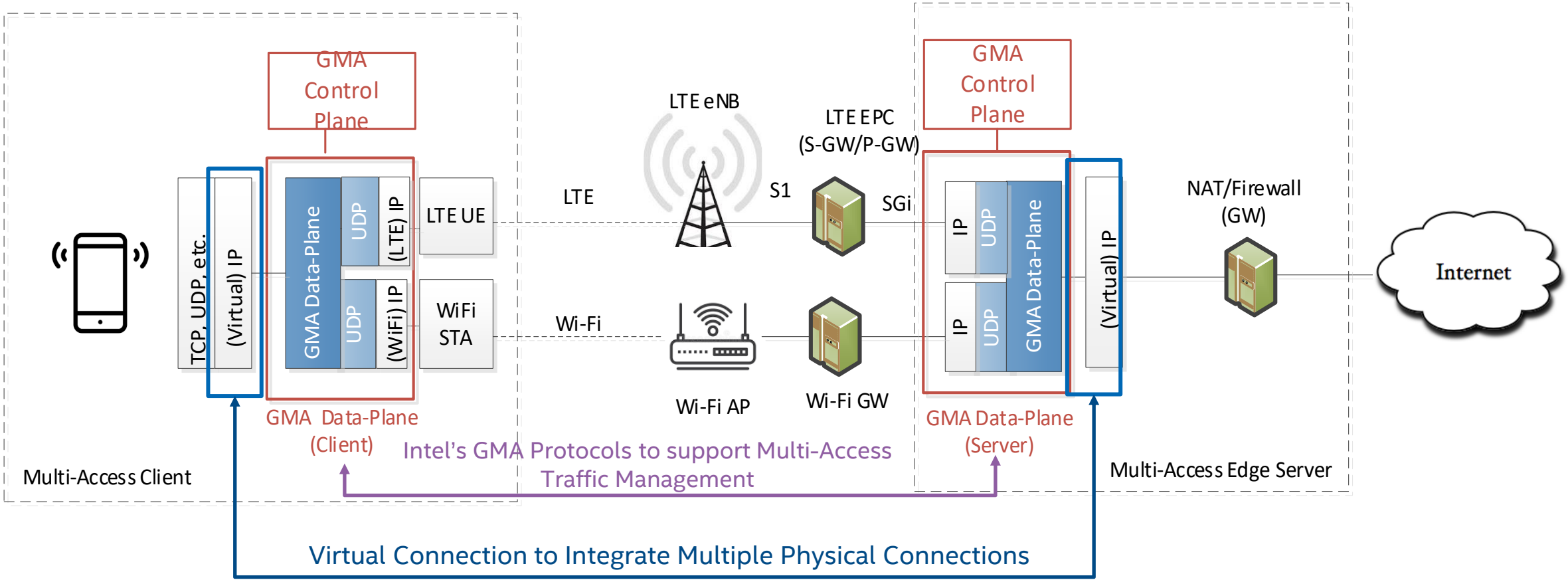


[1]: ETSI/MEC TM APIs (https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=58903)
[2]: ETSI/MEC RNIS API (https://www.etsi.org/deliver/etsi_gs/MEC/001_099/012/02.01.01_60/gs_mec012v020101p.pdf)
[3]: ETSI/MEC WLAN API (https://www.etsi.org/deliver/etsi_gs/MEC/001_099/028/02.01.01_60/gs_MEC028v020101p.pdf)

INT: In-band Network Telemetry
AQM: Active Queue Management
HQoS: Hierarchical Quality of Service

Enable Multi-Access Convergence over ANY Access for ANY Apps

GMA 1.0 Network Reference Architecture



IETF RFC & Drafts on GMA Framework & Protocols:

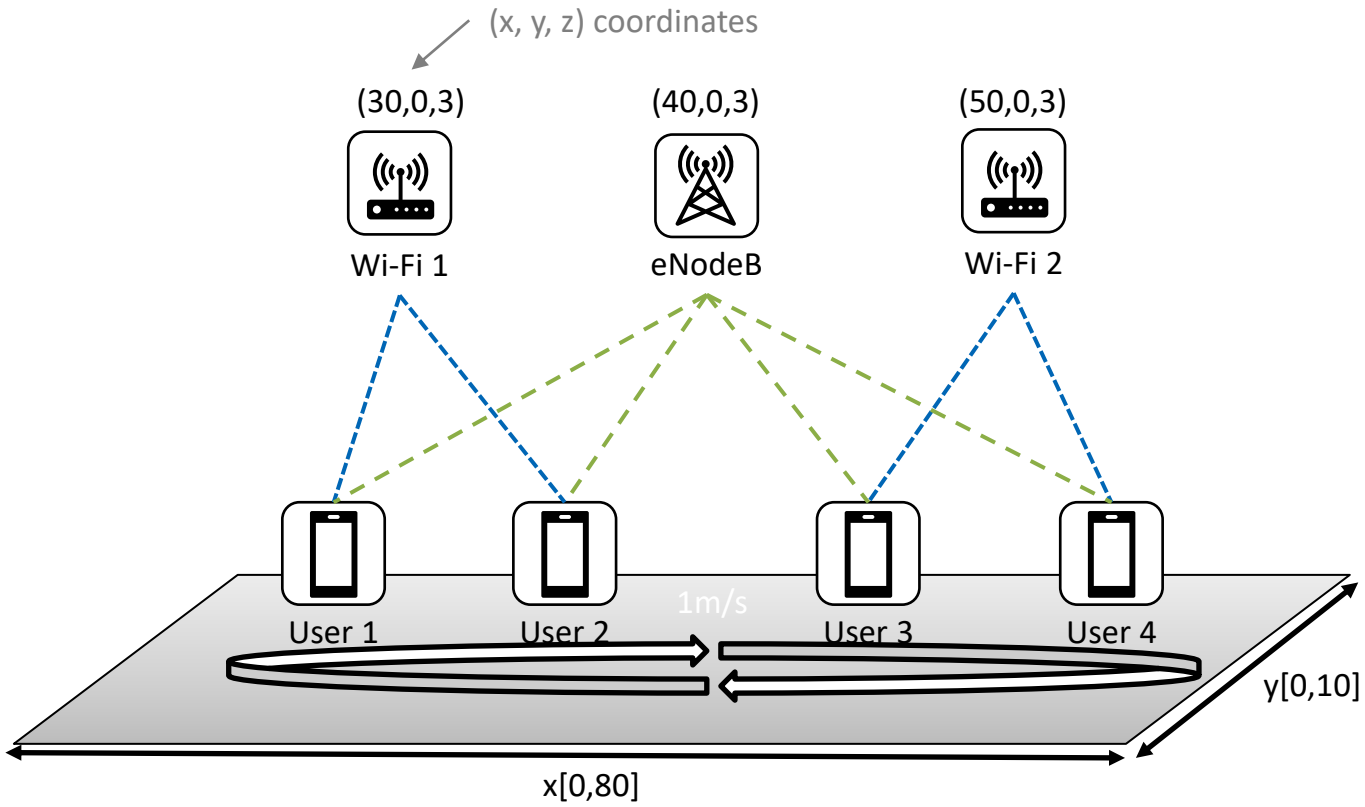
- Multi-Access Management Service, https://www.rfc-editor.org/rfc/rfc8743.txt
- GMA Encapsulation Protocol, https://www.rfc-editor.org/rfc/rfc9188.txt
- GMA Control Protocol , https://www.ietf.org/archive/id/draft-zhu-intarea-gma-control-03.txt

GMA 1.0 Software Release:

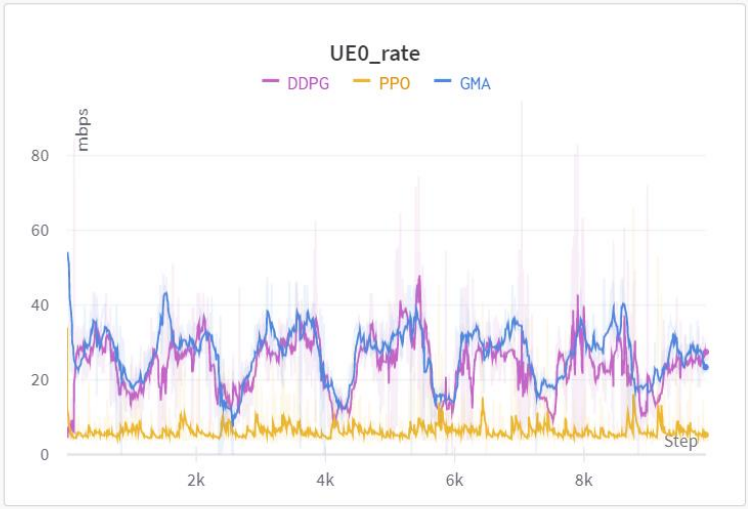
- GMA server: https://www.intel.com/content/www/us/en/developer/articles/reference-implementation/multi-access-with-private-5g.html
- GMA client: https://github.com/IntelLabs/gma

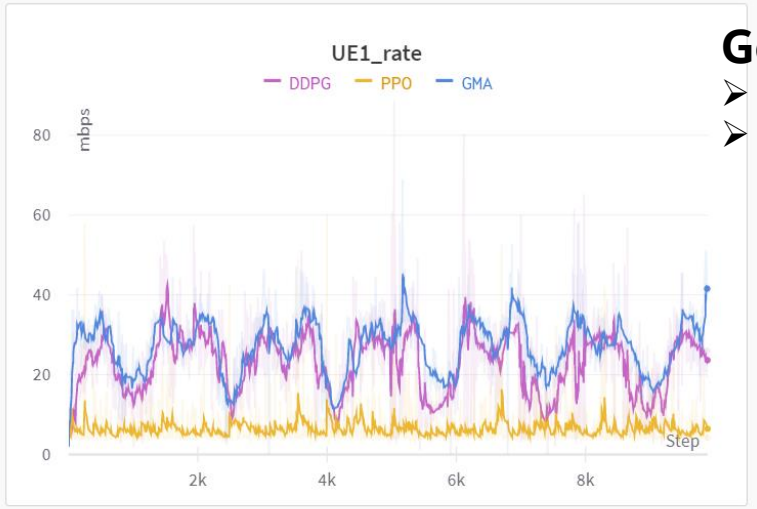
Traffic Splitting Scenario Config

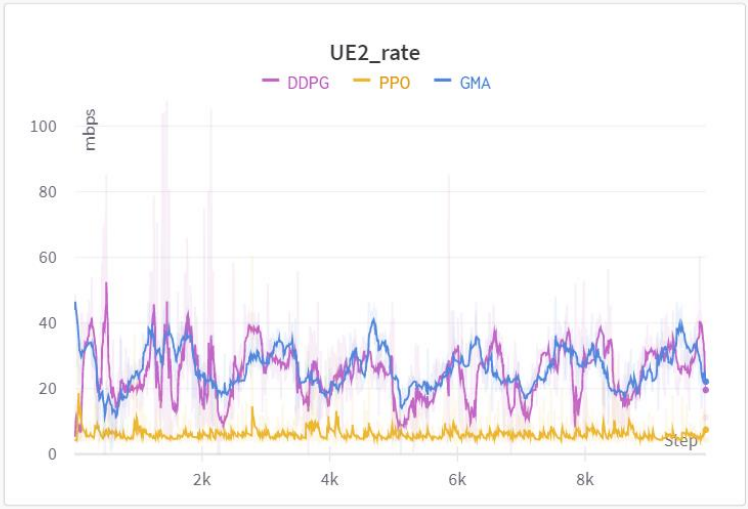
- **1 LTE Cell:** 5MHz(UL) + 5MHz(DL)
- **2 Wi-Fi APs(11ac):** 20MHz + 20MHz
- **Downlink traffic:** TCP Cubic
- **UE Number:** 4
  - with random deployment
- **UE Speed:** 1m/s (left and right)
- **Evaluation Metrics:** Throughput, Delay
  - Baseline: GMA
  - Online RL algorithm: PPO and DDPG

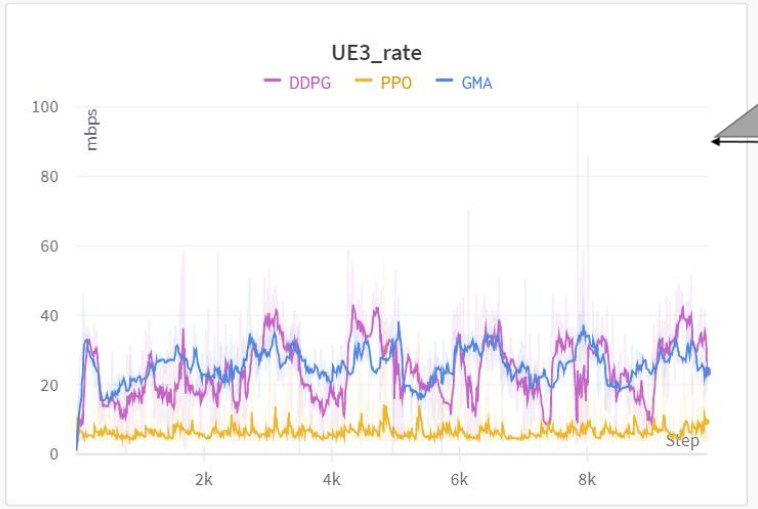


Per User Throughput Comparison



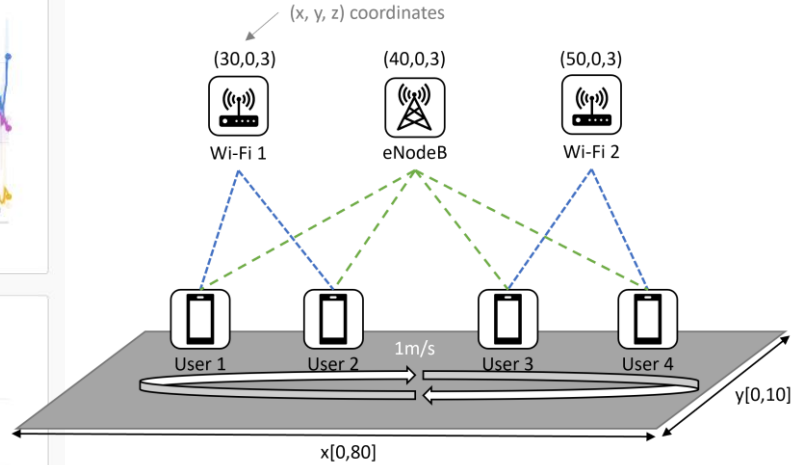






Goal: maximize throughput and minimize delay

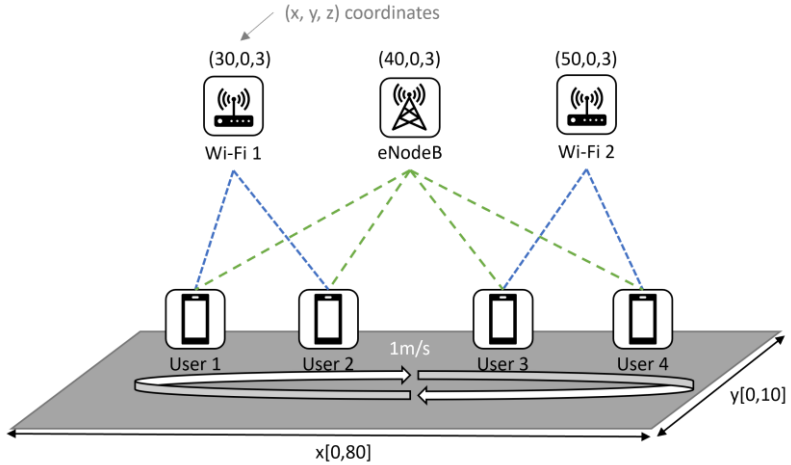
- **Reward**: throughput - delay.
- **States**: LTE and Wi-Fi Max rate



Total Throughput and Delay Comparison

Goal: maximize throughput and minimize delay

- **Reward**: throughput - delay.
- **States**: LTE and Wi-Fi Max rate



Summary

- NetAIGym – an open “Network AI” Simulation-as-a-Service framework
  - NetAISim: ns3-based network simulator with enhanced capabilities, e.g. multi-access, RAN slicing, etc.
  - NetAIServer: the NetAIGym server application software to manage connection and interaction between an NetAIGym client and the NetAISim worker
  - NetAIClient + API: the NetAIGym client application software to configure the simulation and run the “Network AI” algorithms together with the simulation through open API
- A PoC/Trial system available for experiment, support three use-cases: multi-access traffic splitting, QoS-aware traffic steering, and (cellular) RAN slicing
  - limited access available upon request
- How to collaborate and contribute?
  - NetAISim: ns3 modules for new use-cases or capabilities
  - NetAIClient: AI algorithms & models for the existing use-cases

“NetAIGym” is a Use-Case driven “Network AI” Sim-aaS framework, Open for Contributions from the Community