# MQTT broker in C

Eduardo Sandalo Porto

*Department of Computer Science*
*University of São Paulo*

# Project overview

- Implement a very simple MQTT broker
  - TCP, PUB/SUB protocol for IoT
  - Clients subscribe to topics, other clients publish to topics
  - Broker relays messages to subscribers
- Key MQTT operations:
  - Client connection (**CONNECT** packet)
  - Topic subscription (**SUBSCRIBE** packet)
  - Message publishing (**PUBLISH** packet)
  - Topic unsubscription (**UNSUBSCRIBE** packet)
  - Client disconnection (**DISCONNECT** packet)
  - (bonus) Keep-alive pings (**PINGREQ** packet)
- Skip AUTH, QoS, encryption, …

Publishers

Broker

Subscribers
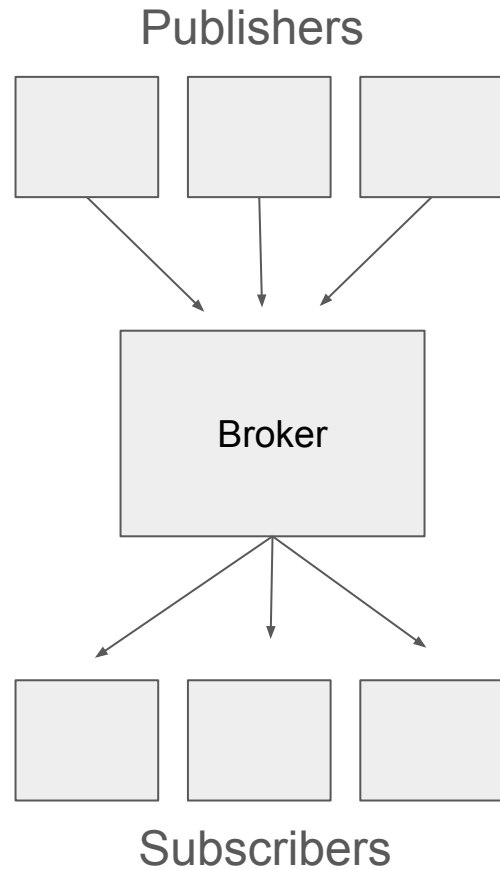
# Architecture

- Concurrency model
  - Each client gets a process
  - Each subscription gets another process
- Messaging and state management
  - Temporary base directory to manage state (`/tmp/temp.mac5910`)
  - Each client gets a subdirectory from base with its process ID
  - Each subscription is managed by a named pipe in client's directory
  - Limitation: separating by / (slashes) harder (did not implement)

```
↳   / ls -R /tmp/temp.mac5910.1.▓▓▓▓▓
5340 5398

/tmp/temp.mac5910.1.▓▓▓▓▓/5340:
topico1 topico2

/tmp/temp.mac5910.1.▓▓▓▓▓/5398:
topico1 topico3
→   / █
```

# Handling connections and subscriptions

- First packet must always be CONNECT
  - Followed by CONNACK
- When a client sends the SUBSCRIBE packet:
  - If the topic file already existed, then the client is already subscribed. Ignore.
  - If it didn't:
    - 1. Create a topic file (named pipe) in the client's directory
    - 2. Fork a process to read the pipe
    - 3. Use `select` on the pipe to read or check with a timeout if it has been deleted
  - Subscription processes can stop on their own when a pipe is deleted
  - Subscription processes allow clients to send more packets (non-blocking)
- When a client sends the UNSUBSCRIBE packet:
  - Delete the topic file, automatically stopping the subscription process

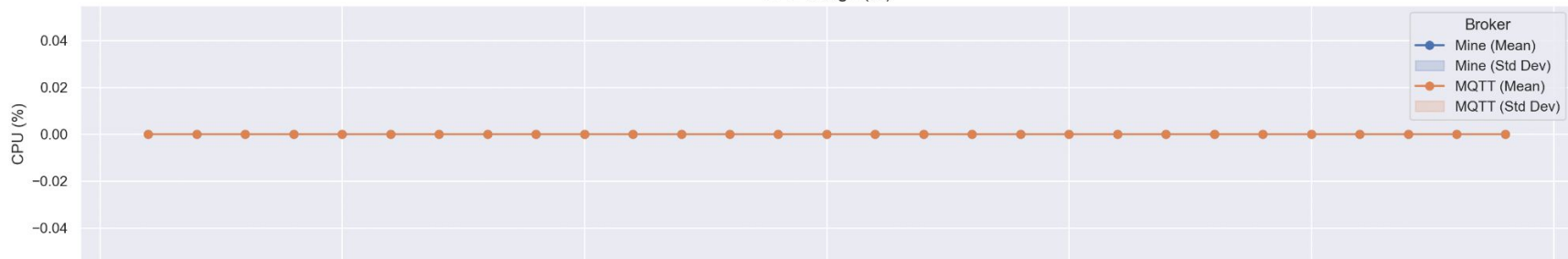# Handling publishing, disconnecting, and pinging

- When a client sends a PUBLISH packet:
  - Broker will search for all named pipes whose name include the topic
    - `/tmp/temp.mac5910/<id>/<topic>`
  - Broker will write the message to each pipe
  - Subscriber processes will handle sending messages to subscribers
  - Weird behavior: PUBLISH packets may be followed by 2-byte DISCONNECTs
- When a client sends a DISCONNECT packet:
  - Delete their folder, automatically stopping all subscriber processes (where applicable)
- When a client sends a PINGREQ packet:
  - Just answer with a PINGRESP
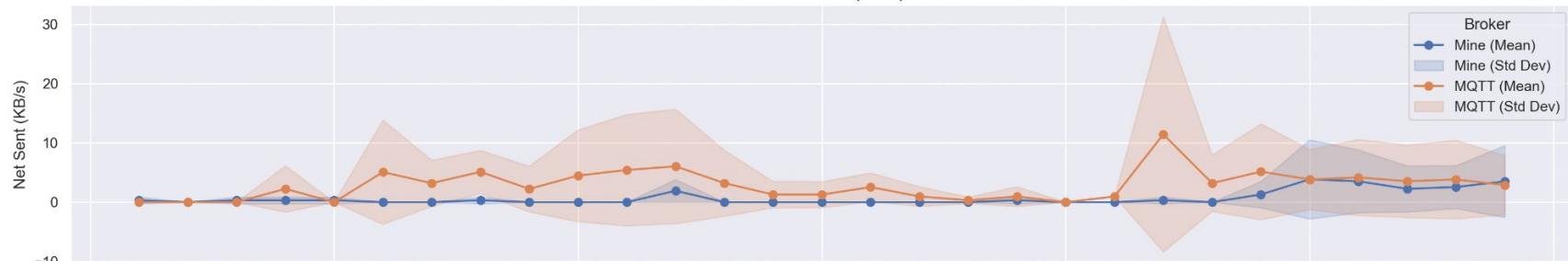
# Performance analysis: setup

- Three experiments comparing CPU and net usage with *mosquitto*:
  - 1. Idle server with no clients connected
  - 2. 50 subscribers, with 50 publishers each sending 3 PUBLISH
  - 3. 500 subscribers, with 500 publishers each sending 3 PUBLISH
- Test environment:
  - Broker: MacBook Air M2, 16GB RAM, macOS 15.6.1
  - Clients: Dell Vostro 15 5510, 20 GB RAM, Ubuntu 24.04 LTS through WSL2
  - Router: Samsung Galaxy S20 FE (yes, a smartphone!)
- Methodology
  - Automated scripts in Python to collect data through `psutil`
  - Metrics: CPU usage and network throughput
  - Results are the mean of three executions with standard deviation

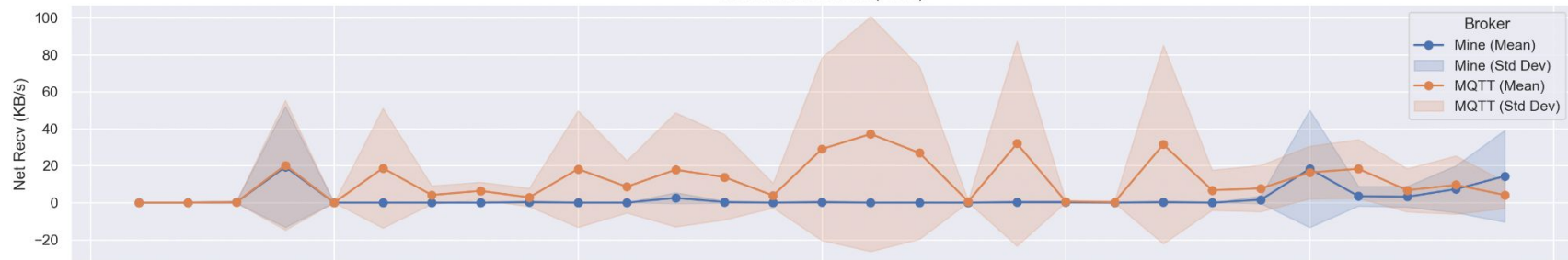Mean Performance with Standard Deviation - Experiment 1

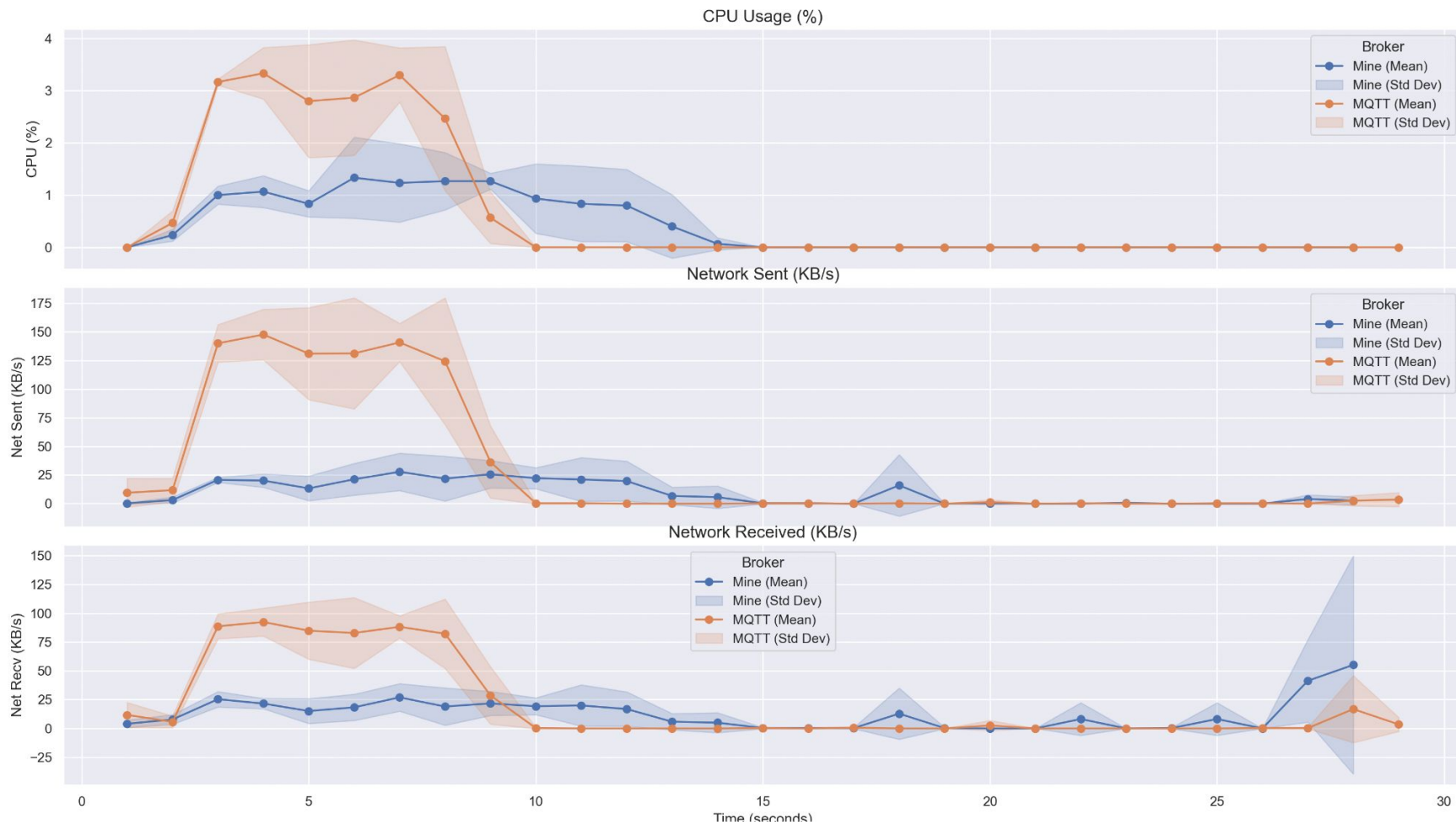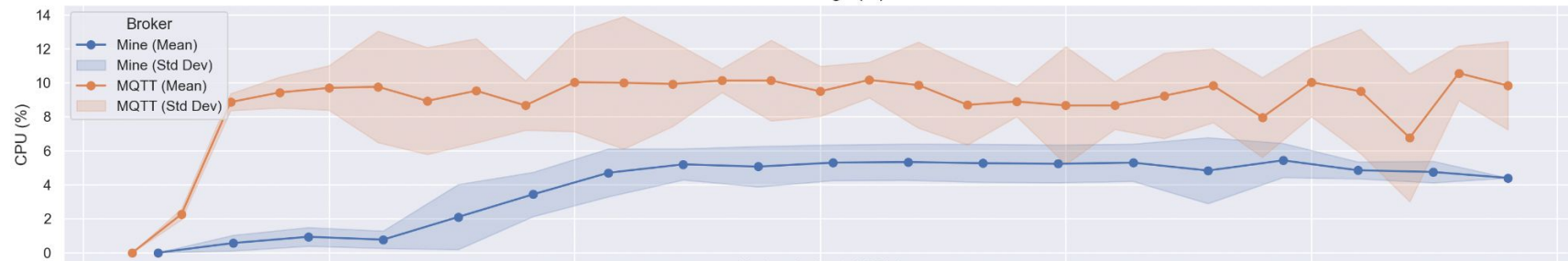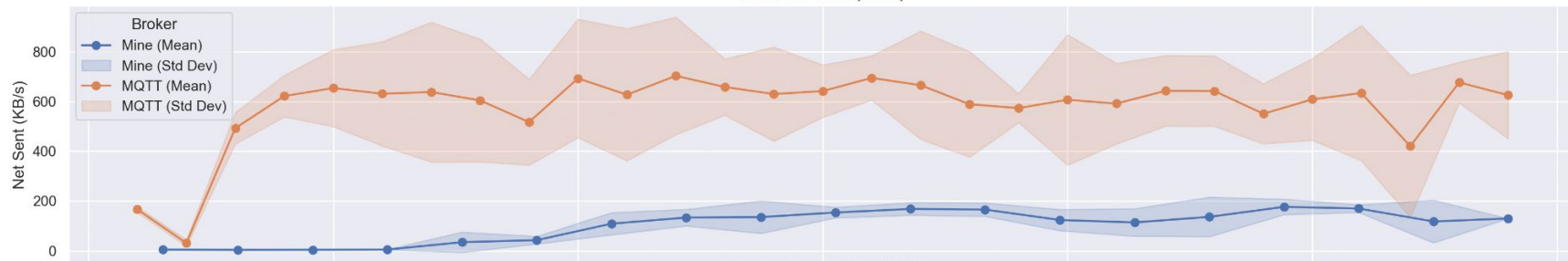Mean Performance with Standard Deviation - Experiment 2

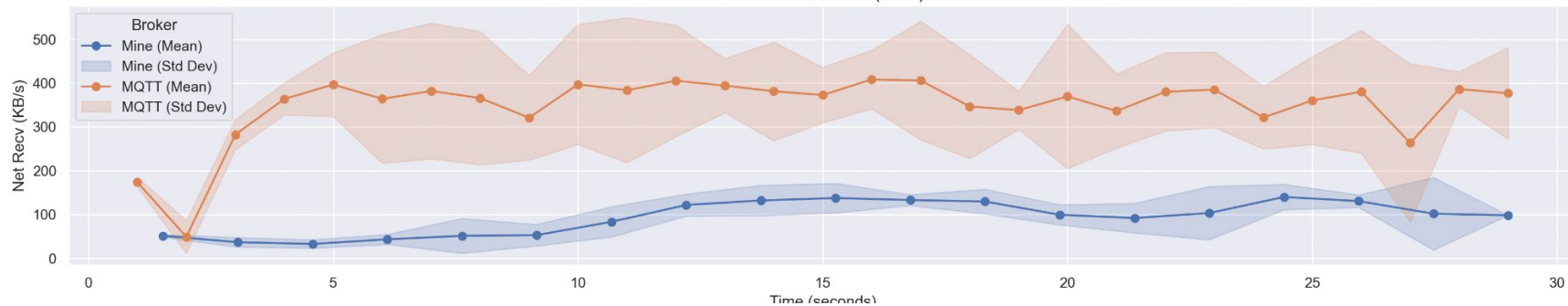**Mean Performance with Standard Deviation - Experiment 3**

CPU Usage (%)

Network Sent (KB/s)

Network Received (KB/s)

# Strengths and weaknesses

- Strengths
  - Fork and pipe-based is easy to implement
  - Isolates clients quite well, *hopefully* not causing failure in a client to affect another
- Weaknesses
  - Very poor scalability
    - As more and more processes are created, the slower everything gets
  - File system I/O is always slower than in-memory
  - Mass process creation slows down the system due to priority shifting
    - Can be seen in the last experiment: less analytics generated, since the analytics process got less priority

# Conclusion

- The MQTT implementation works, although is slow or fails with large amounts of connections
- Design is simple, but not scalable nor performant
- Unable to match *mosquitto*