Optimizing IoT Cloud Applications for Scalability:

Leveraging RPC with Distributed Queues for Seamless Operations

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DC - UFSCar, 2025
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Agenda

Introduction

Objectives

Theoretical Basis

Development

Homologation & Results

Conclusions

Introduction

Introduction

IoT & Cloud

- Volume, Velocity, Variety
- Real-Time and Low Latency
- Bidirectional Communication
- Faulty Connections
- Heterogeneous Workloads

Introduction

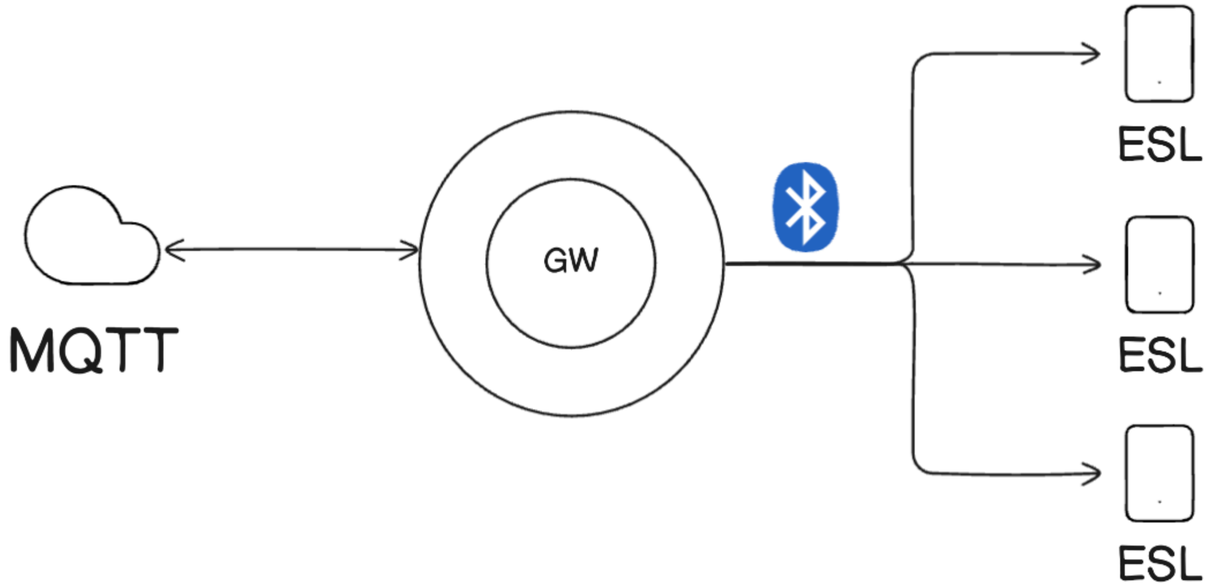
Infrastructure as a Service (IaaS) & Elasticity

- Pay-as-you-go Model
- Managed Components
- Horizontal Scalability

Introduction

The ESL Problem & MQTT Limitations

- Massive Scale
- Traditional Broker Hurdles
  - MQTT struggles with bidirectional communication and the request-reply pattern needed for RPCs when horizontal scaling is applies



Objectives

Objectives

Building a Scalable IoT Communication Backbone

- Building a Scalable IoT Communication Backbone
  - Develop a functional MVP for large-scale IoT device networks tested using ESLs
- Elastic and Scalable Architecture
- Serve as base and reference for future projects requiring a quickly deployable IoT communication backbone with minimal configuration, easily adaptable to other product niches

Theoretical Basis

Theoretical Basis

Theoretical Foundations

- IoT Ecosystems
  - **Sensors** Collect Data; **Actuators** execute physical actions (our focus)
  - **Gateways** act as intermediaries, enabling diverse protocols such as Bluetooth Low Energy (BLE) etc.
- Scalability
  - **Vertical Scaling** (Scale-Up): Increasing single machine capacity (limited, single point of failure)
  - **Horizontal Scaling** (Scale-Out): Distributing workload across multiple machines (virtually limitless, fault-tolerant, cost-effective)

Theoretical Basis

Core Technologies and Concepts

- Cloud Computing
  - **Definition**: On-demand access to shared, configurable computing resources
  - **Elasticity**: The system’s ability to automatically adjust resources to match fluctuating workloads, optimizing performance and cost

Theoretical Basis

Core Technologies and Concepts

- Message Queues and Asynchronous Communication
  - **Message Brokers** (Queues): Producers send messages, Consumers receive them, in our case RabbitMQ
  - **Load Balancing** and **Buffering**: Handle traffic bursts, prevents consumer from being overwhelm.
  - **Asynchronous Communication**: Producers don’t wait for execution, only broker (queue) confirmation, enables decoupled operation
  - **AMQP**: Open Standard for reliable, asynchronous message transfer
  - **MQTT**: Lightweight, publish-subscribe protocol ideal for IoT

Theoretical Basis

Core Technologies and Concepts

- Remote Procedure Call (RPC)
  - Allows programs to call producers
- In-Memory Data Stores
  - Extremely fast data access (low latency, high throughput)
  - Stores data in RAM, ideal for real-time applications and temporary storage
  - Highly amenable to horizontal scalability

Theoretical Basis

Methodology and Testing Approach

- Flexible Scalability
  - Custom Communication Backbone is designed for Cloud-Native and automatic adaptation to real-time, varying demand
- Comprehensive Testing Strategy
  - Combines quantitative performance measurements and qualitative operational observations
    - Latency, Throughput
    - Ease of setup, configuration overhead

Development

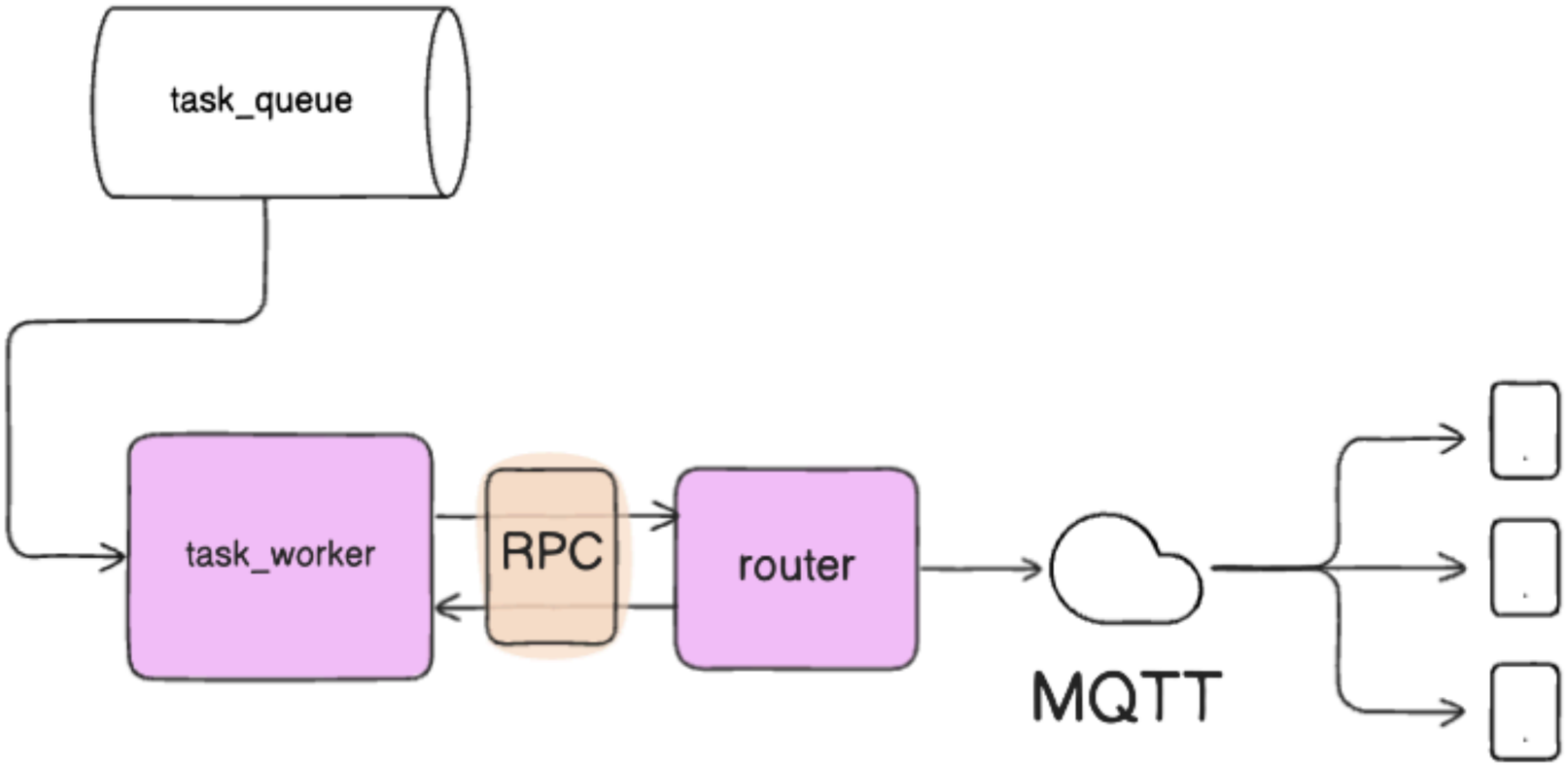
Development

General Architecture

- Async:
  - Long-Running Tasks: ESLs actions can take up to three minutes to complete
  - Decoupling and Resilience
  - Delivery Guarantees: Ensures at-leas-once execution semantics

Development

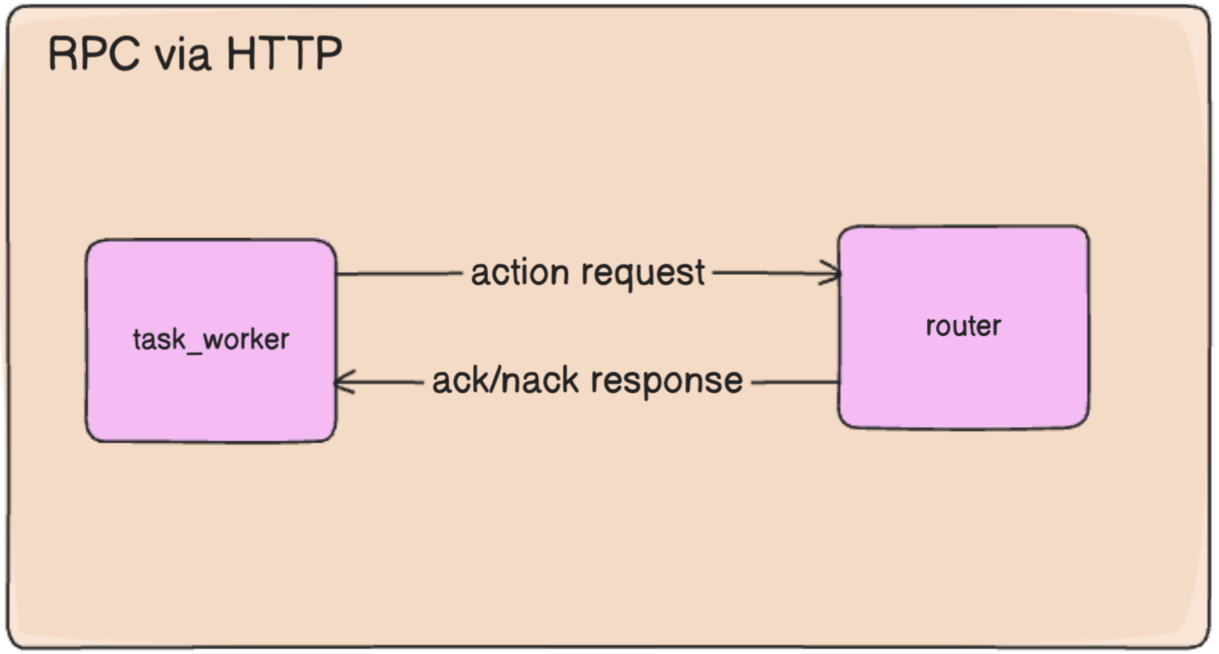
General Architecture



Development

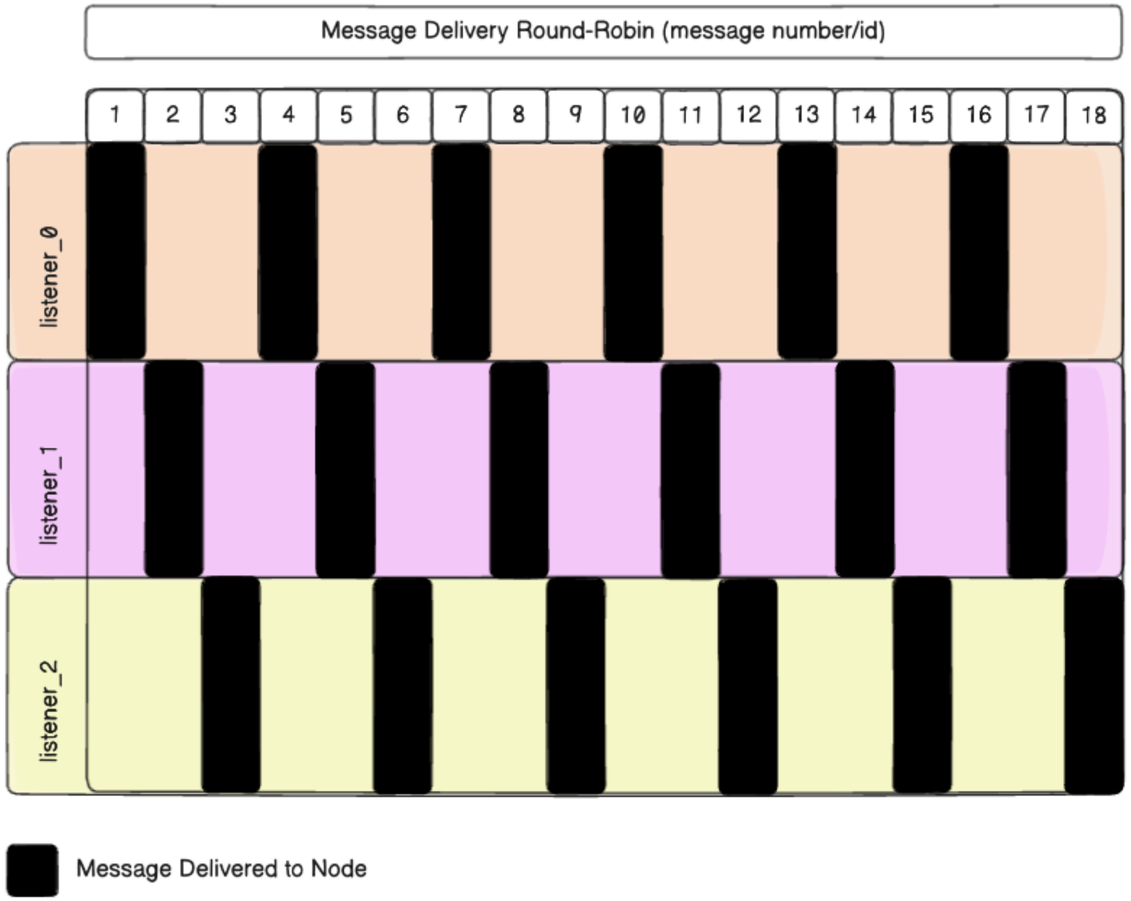
Baseline Backbone

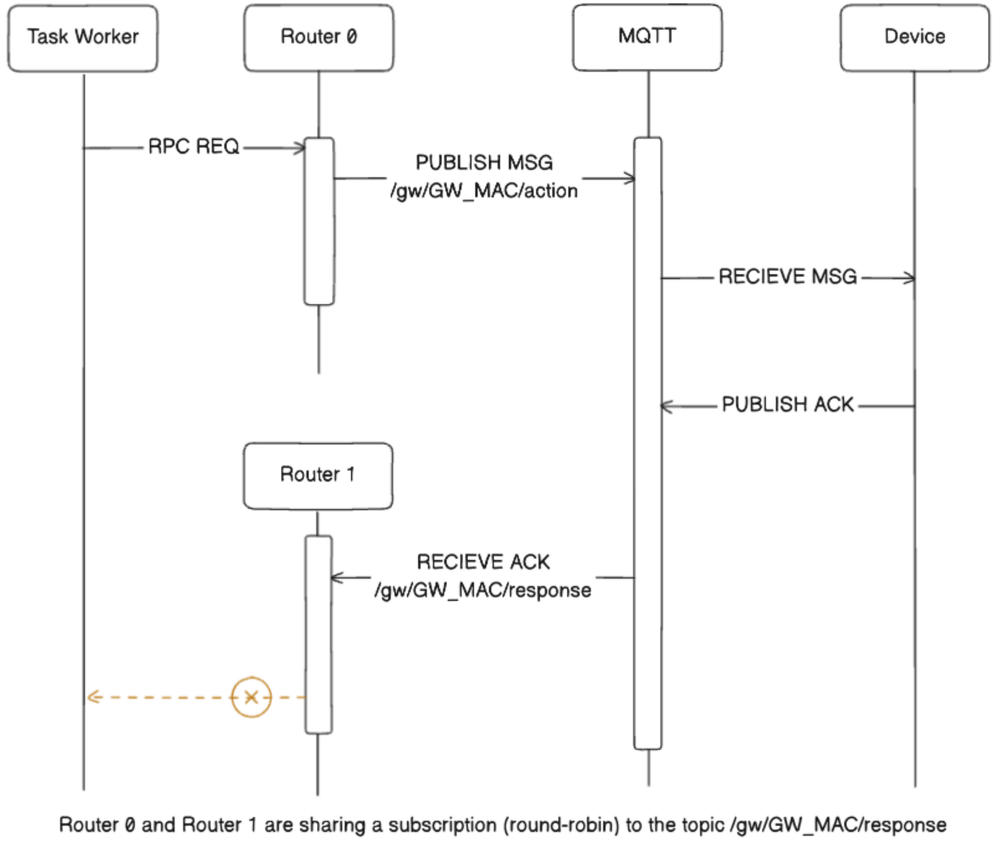
- RPC via HTTP
- Limitation: The MQTT protocol’s round-robin load balancing
  - Leads to misrouted requests, breaking the request-reply pattern
  - Forces static binding **1:1** between each **router** and **gateway**



Development

Baseline Backbone



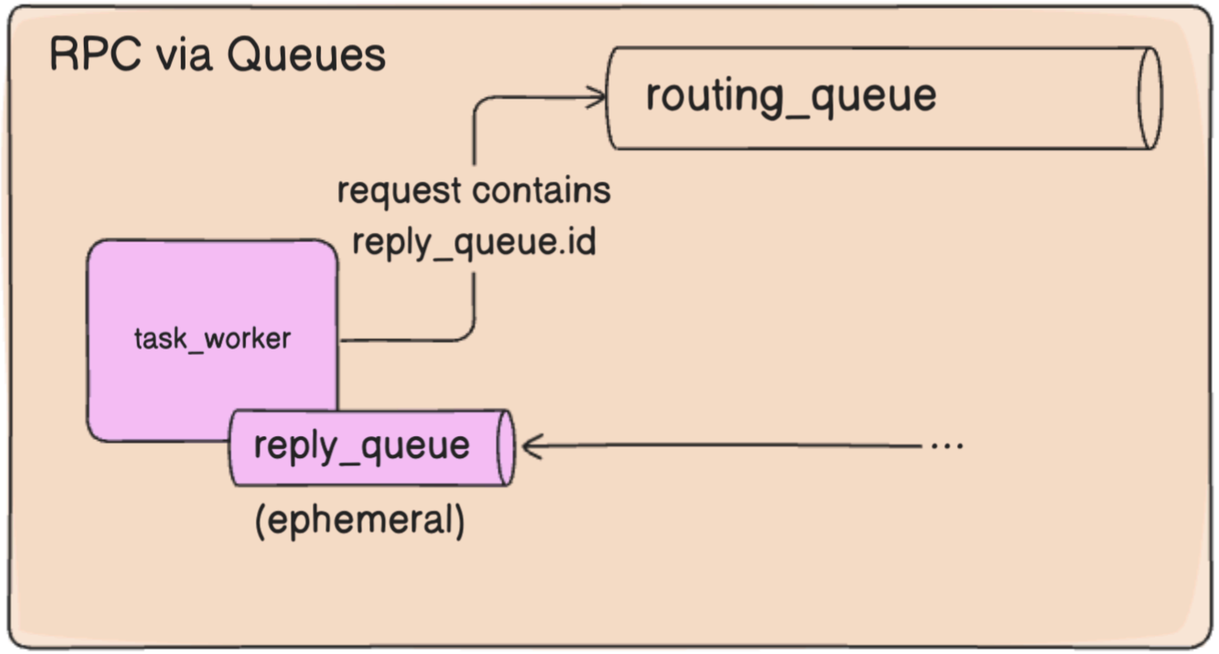


Router 0 and Router 1 are sharing a subscription (round-robin) to the topic /gw/GW_MAC/response

Development

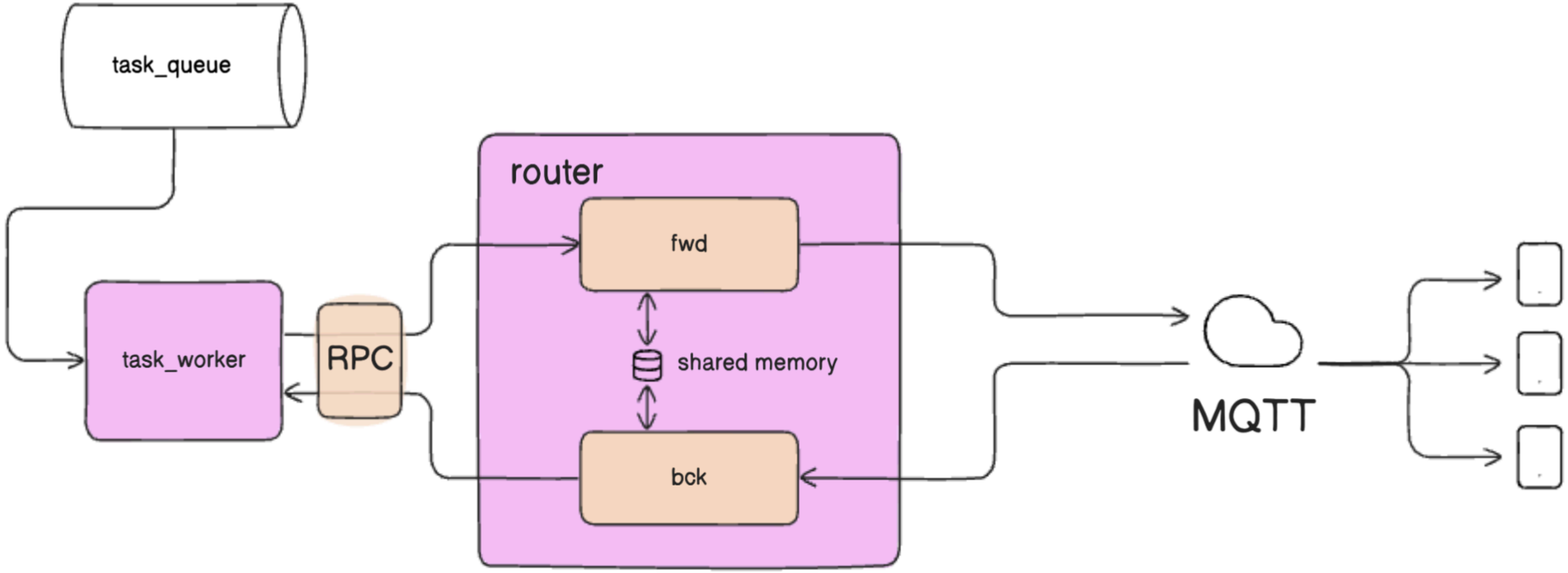
Custom Backbone

- Replies are directed to a specific reply queue using RequestId
- Eliminates sticky sessions, allowing multiple routers to share single gateways load
- Shared Memory via redis



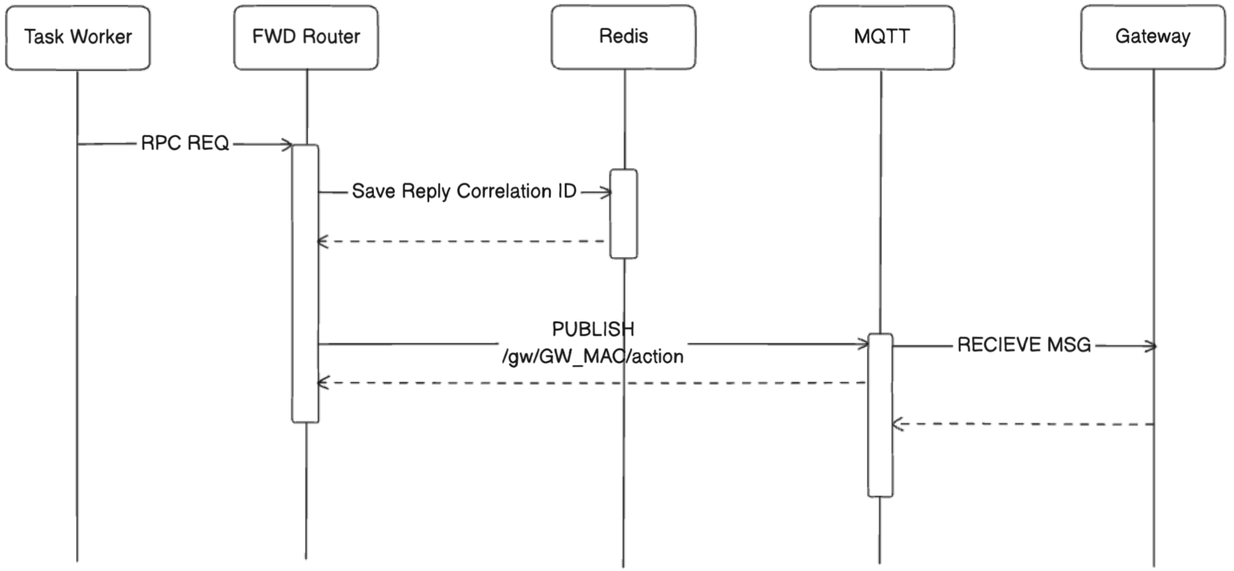
Development

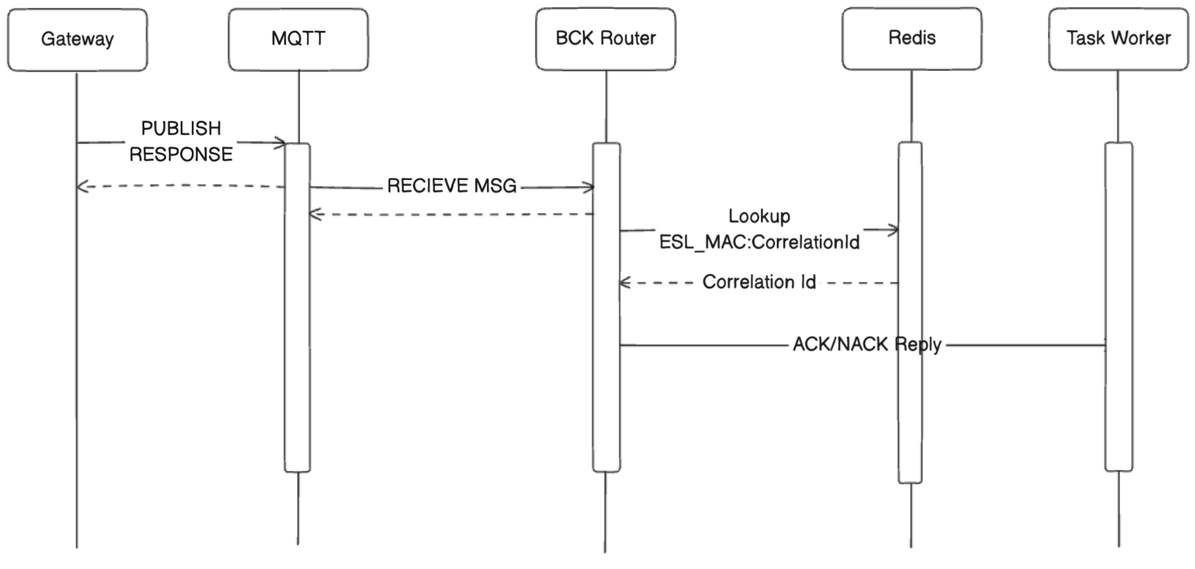
Custom Backbone



Development

Custom Backbone





Development

Pseudo Code

```
// task_worker
func main() {
    for task := range rabbitMqMsgsChan {
        esls := dbService.BusinessLogic(tasks)

        var msgs []models.RoutingMessage
        for esl := range esls {
            m := models.RoutingMessage{}.FromEsl(esl)
            msgs = append(msgs, m)
        }

        reps := commsBackbone.Forward(msgs) // This method waits for replies
        if len(reps) != len(macs) {
            return errors.New("not all devices replied")
        }
    }
}
```

Development

Pseudo Code

```
// fwd_router
func main() {
    for routingMsg := range rabbitMqMsgsChan {
        sharedMem.Save(routingMsg.EslMac, routingMsg.CorrelationId)

        gwMac := dbService.GetRoute(routingMsg.EslMac)
        topic := "/gw/"+gwMac+"/action"

        mqtt.Publish(topic, routingMsg)
    }
}
```

Development

Pseudo Code

```
// bck_router
func onMsgCallback(rep models.RoutingReply) {
    correlationId := sharedMemService.RepKey(rep.EslMac)
    messagingService.Reply(correlationId, rep)
}

func main() {
    topic := "/gw/+/response"
    mqtt.SetCallback("$share/router-bck-group/", onMsgCallback)
    mqtt.Start() // Hangs
}
```

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Homologation & Results

Homologation and Results

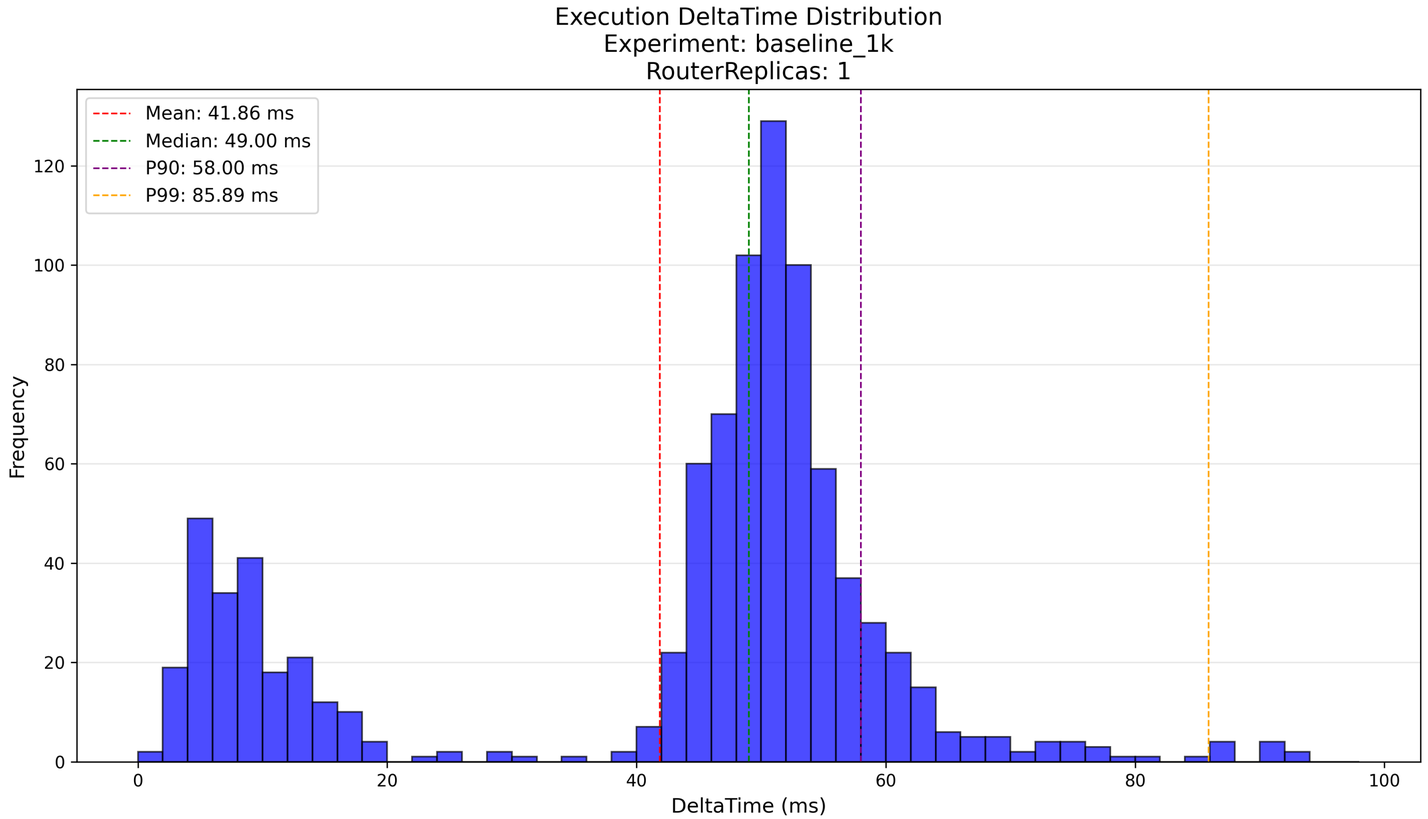
Testing Setup & Methodology

- Test Environment
  - 12-core machine, 16GB RAM
  - **Router Elements**: CPU capped at 100mCPU per replica
  - Other systems had no resource limits
- Load Generation
  - 50 concurrent workers to load routers; 60s timeout
- Data Collection
  - Telemetry on worker-side to collect end-to-end latency

Homologation and Results

Functional Tests - Baseline System

- Verifying Core Operations (1k tasks, 1 Router Replica)
  - Confirm the systems correctly follow the architectural sequence diagram



Homologation and Results

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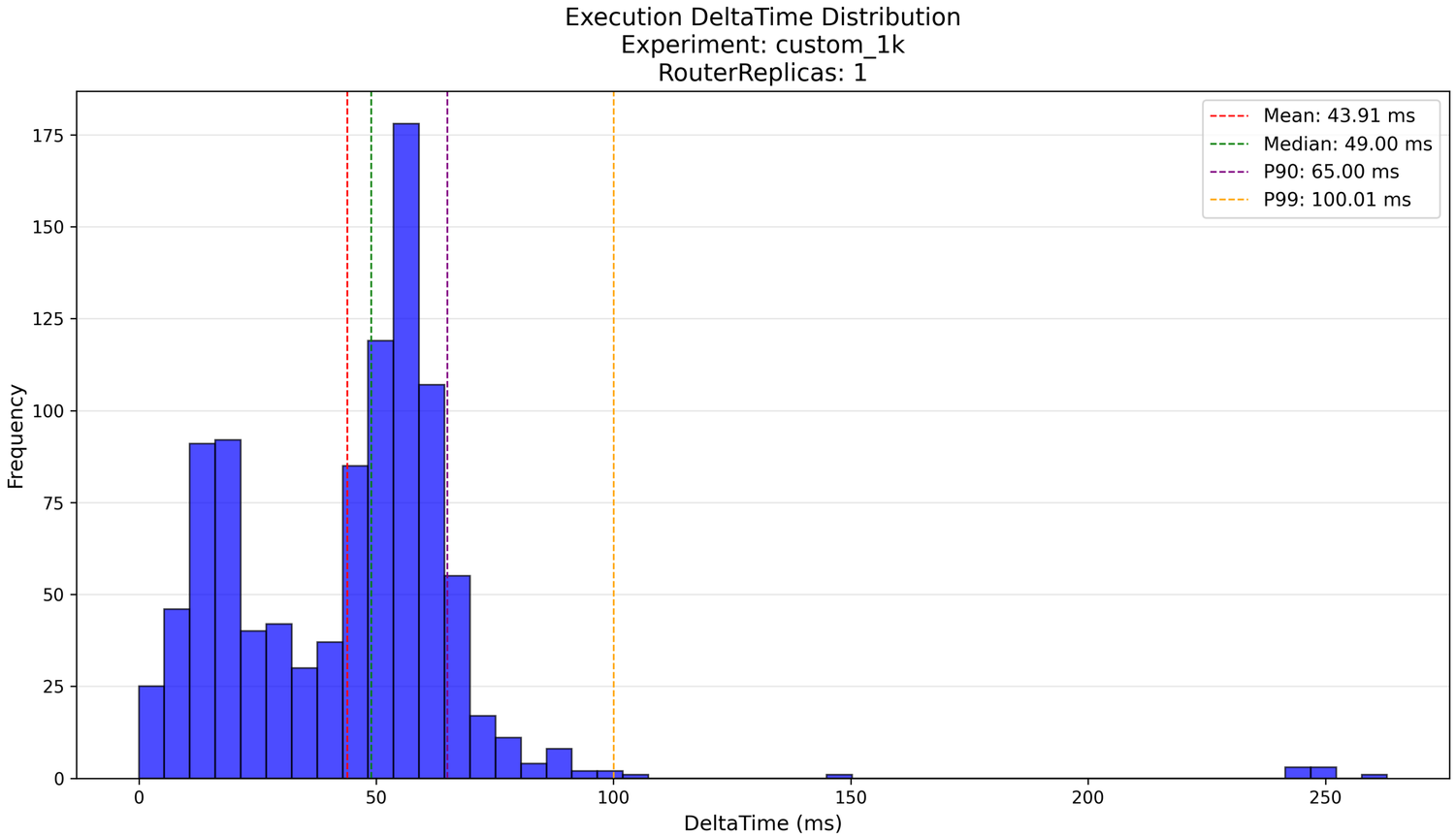
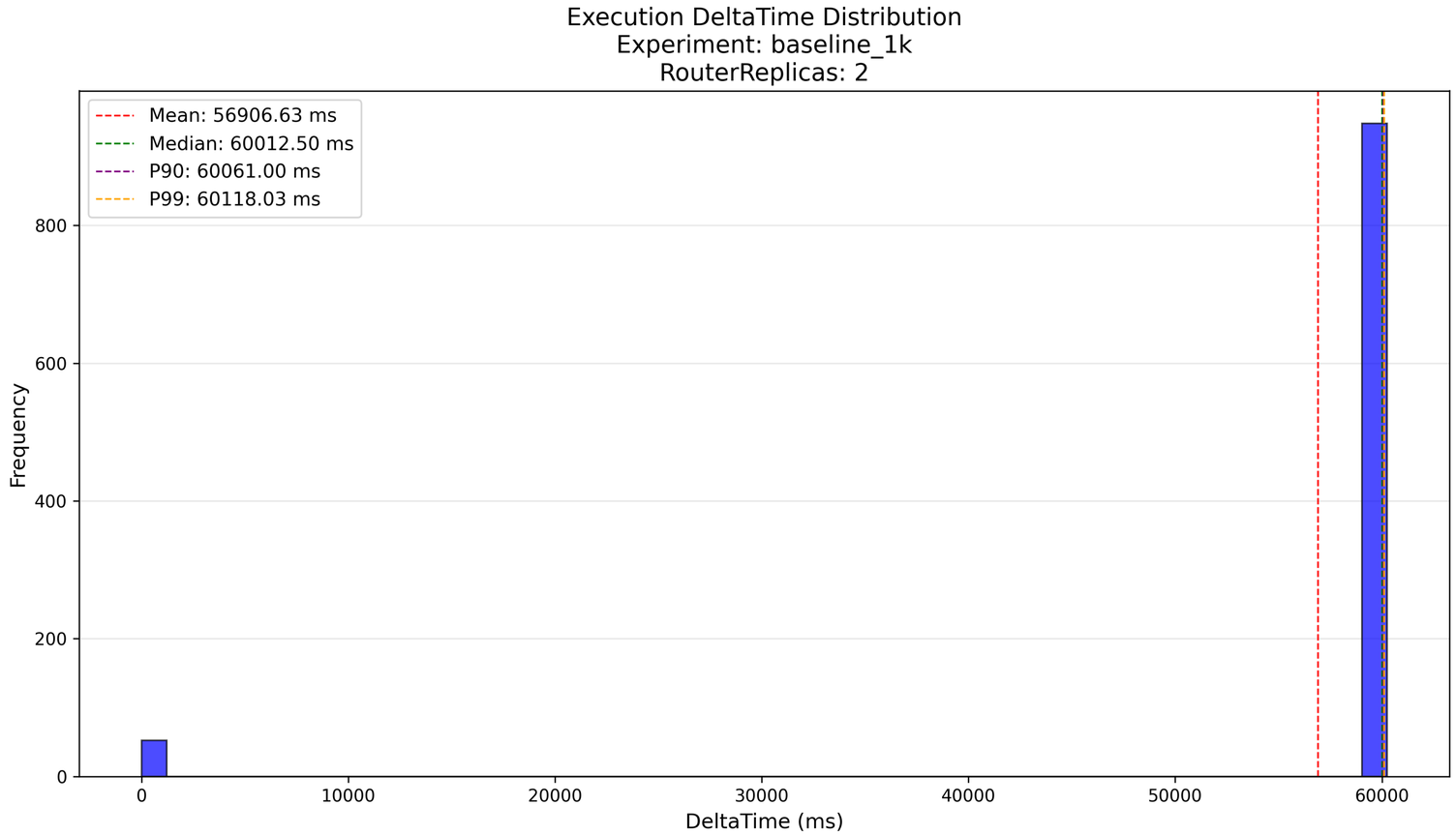


Homologation and Results

Performance/Scalability Tests - Baseline System

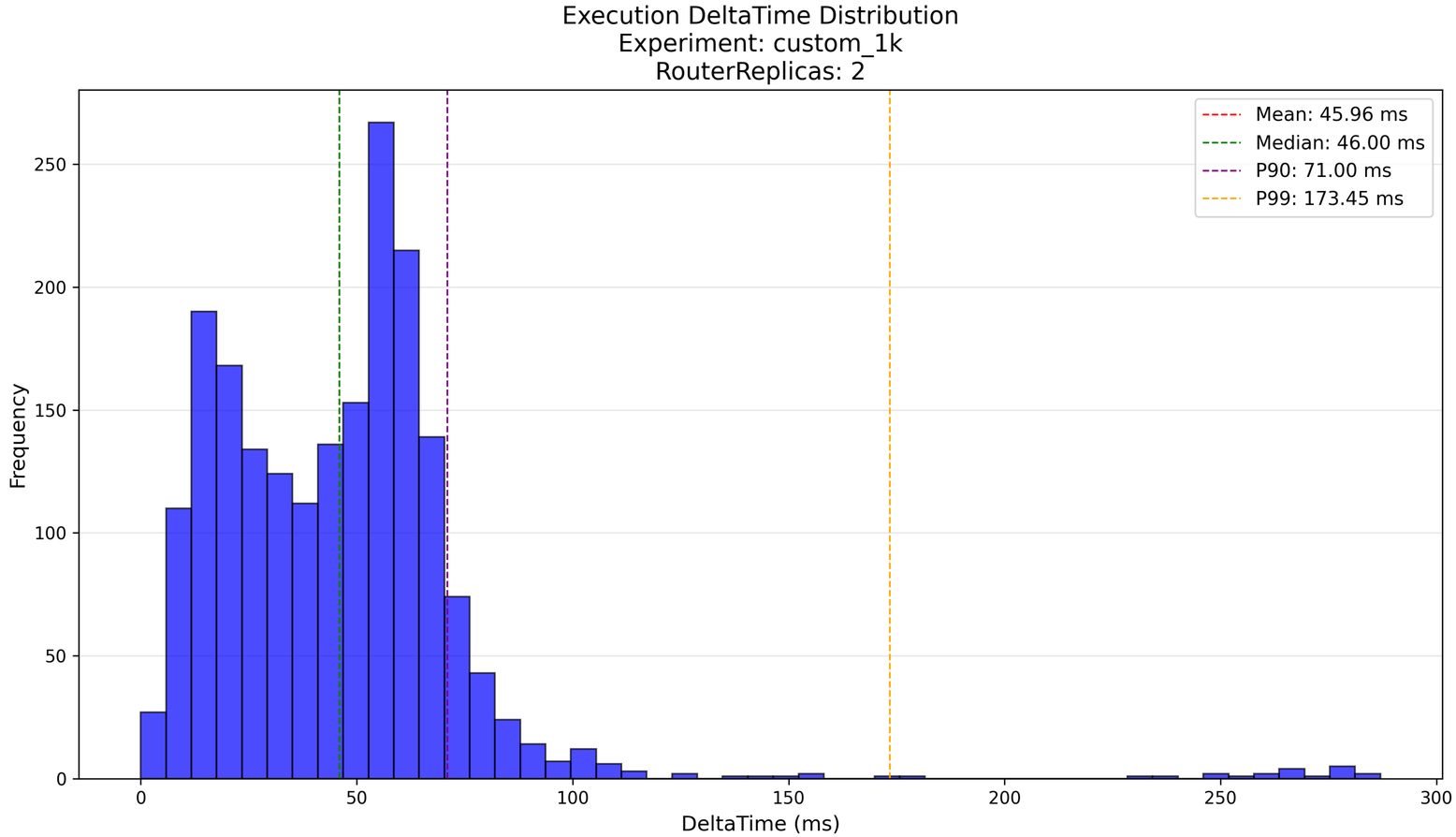
- Verifying Scalability (1k tasks, 2 Router Replicas)
  - **Misrouting Pitfall**: Requests timed out



Homologation and Results

Performance/Scalability Tests - Custom System

- Verifying Scalability (1k tasks, 2 Router Replicas)
  - Correctly routes replies to the requesting worker

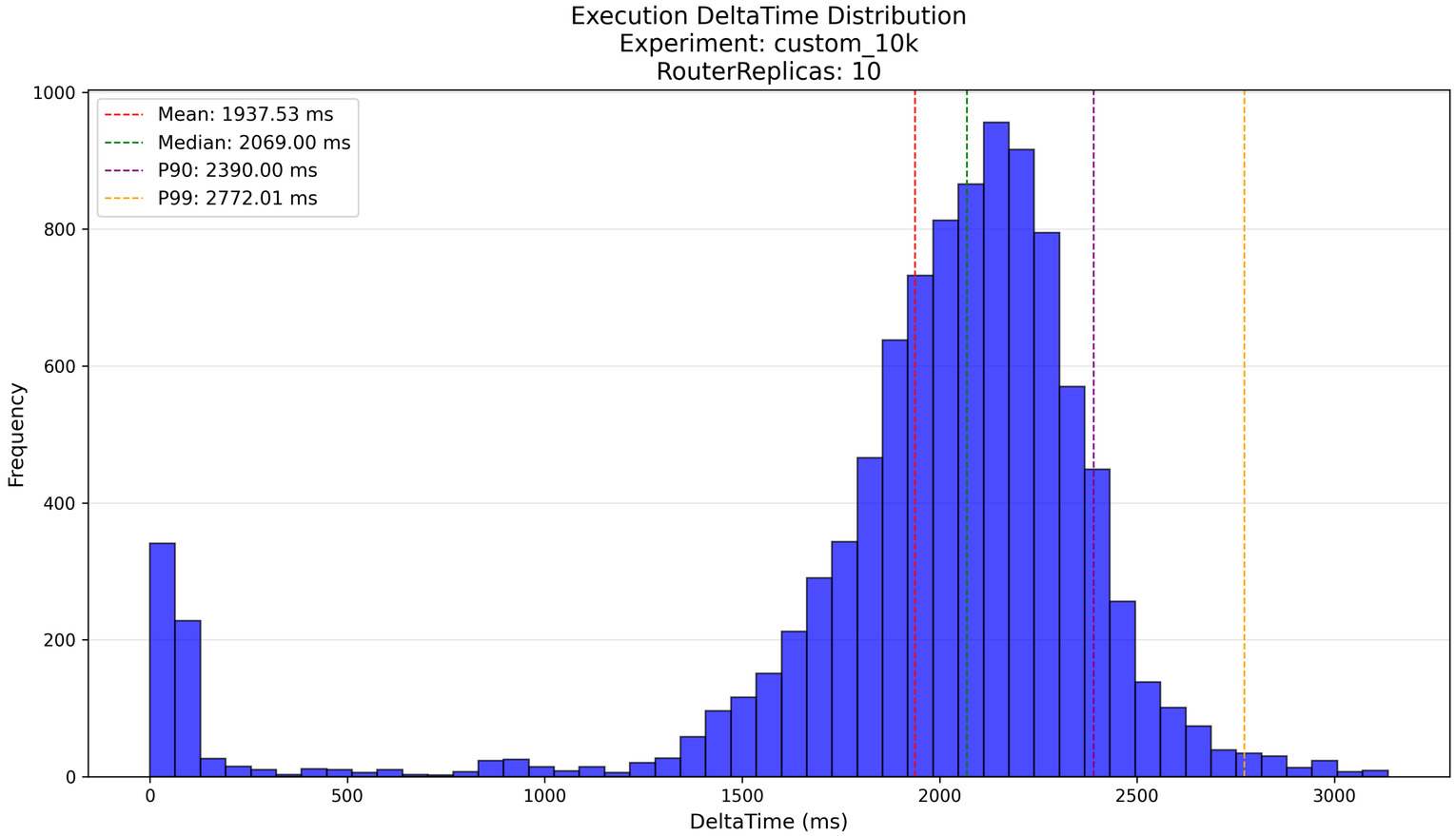


WE WILL NOT CONTINUE PERFORMANCE TESTS ON THE BASELINE SYSTEM

Homologation and Results

Performance/Scalability Tests - Baseline System

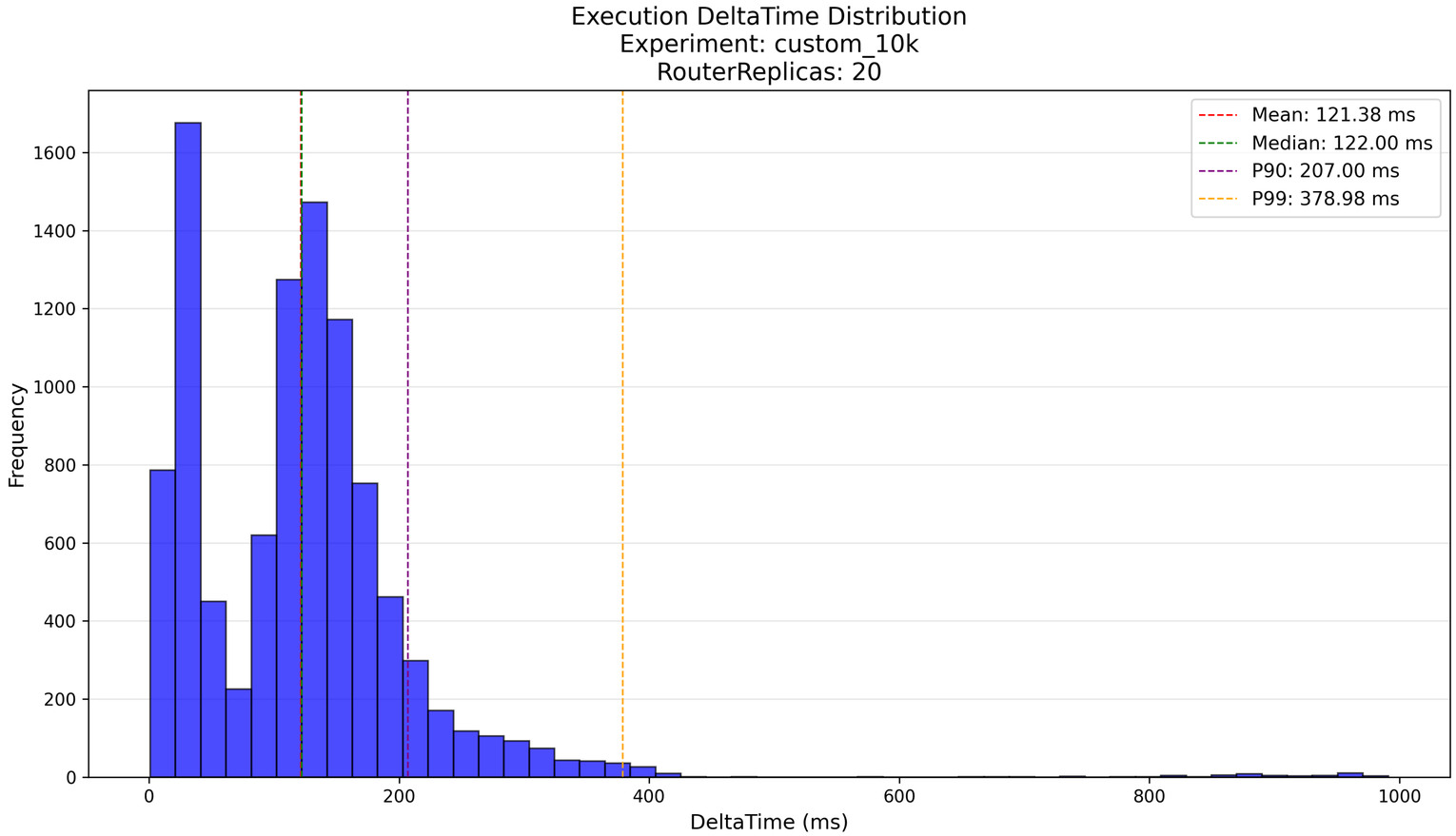
- Verifying Performance (10k tasks, 2 Router Replicas)
  - Increase in latency, system starting to bottleneck



Homologation and Results

Performance/Scalability Tests - Baseline System

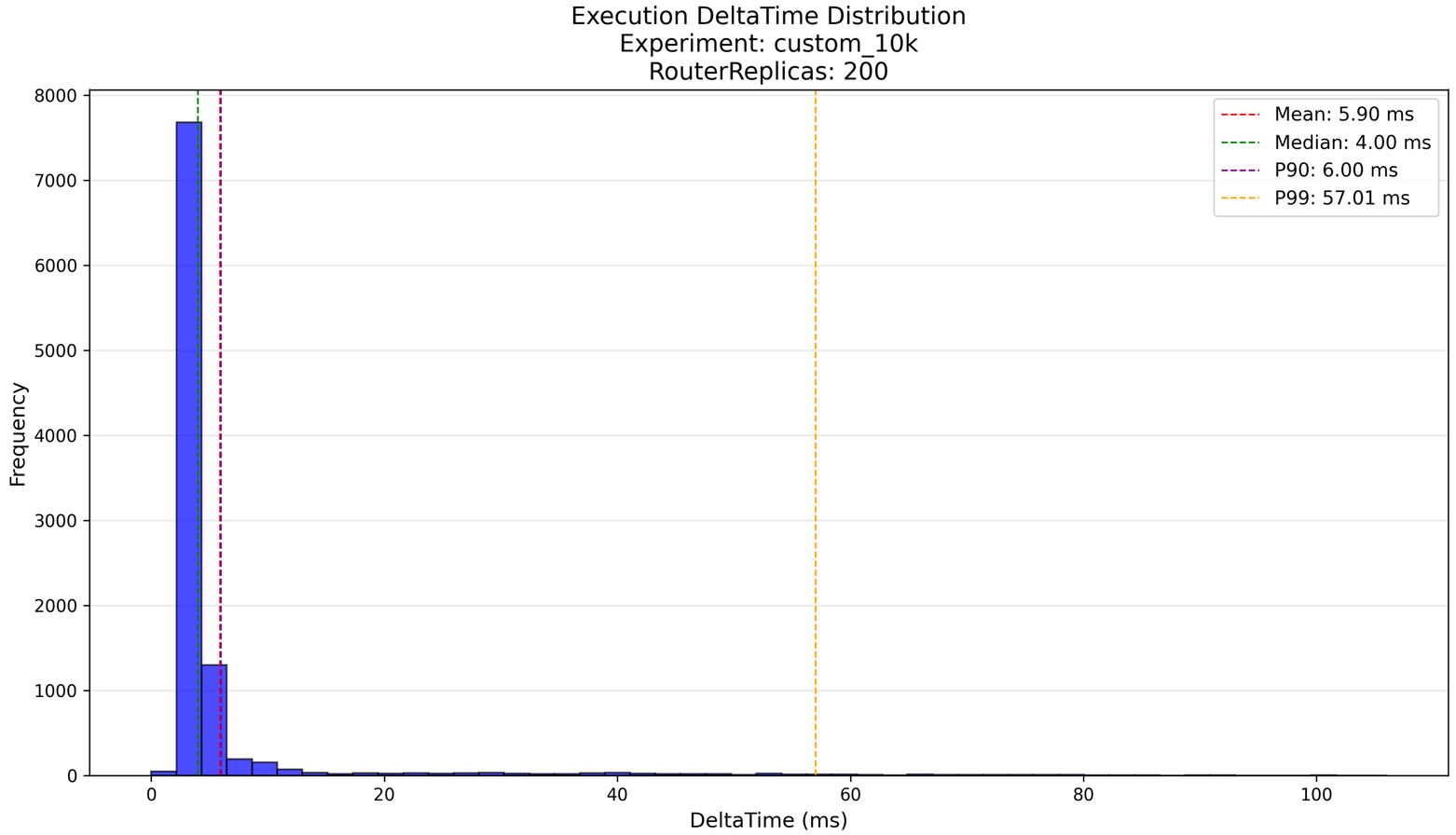
- Verifying Performance (10k tasks, 20 Router Replicas)
  - Latency reduced back to acceptable values



Homologation and Results

Performance/Scalability Tests - Baseline System

- For Fun Experiment, Stretch (10k tasks, 200 Router Replicas)
  - Latency greatly reduced



Conclusions

Conclusions

Achieving a Scalable and Cloud-Native IoT Communication Backbone

- MVP Success
  - Developed System fully executes all architectural sequences
  - Exceptional Scalability, true Elasticity
- Cloud-Native Design
  - Developed using modern, well-established technologies (Go, RabbitMQ, Redis, MQTT, Docker)
  - Strategic choisi makes the system Cloud-Native by design

IoT Communication Backbone

Demo

github.com/LombardiDaniel/TCC