Response Time Analysis for RT-MQTT Protocol Grounded on SDN

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Introduction

- Industry 4.0 and IIoT in Industrial Operations:
  - **Improvements:** scalability, transparency, agility, flexibility and efficiency
  - **Requirements:** timing behaviour, high predictability and stability

- Why MQTT?
  - It is a most popular **application-layer protocol** in (I)IoT applications:
    - ✓ Simplicity, low footprint and scalability
    - ✓ Effective publisher-subscriber capability

- MQTT Limitation:
  - It **misses** support for **real-time** behaviour

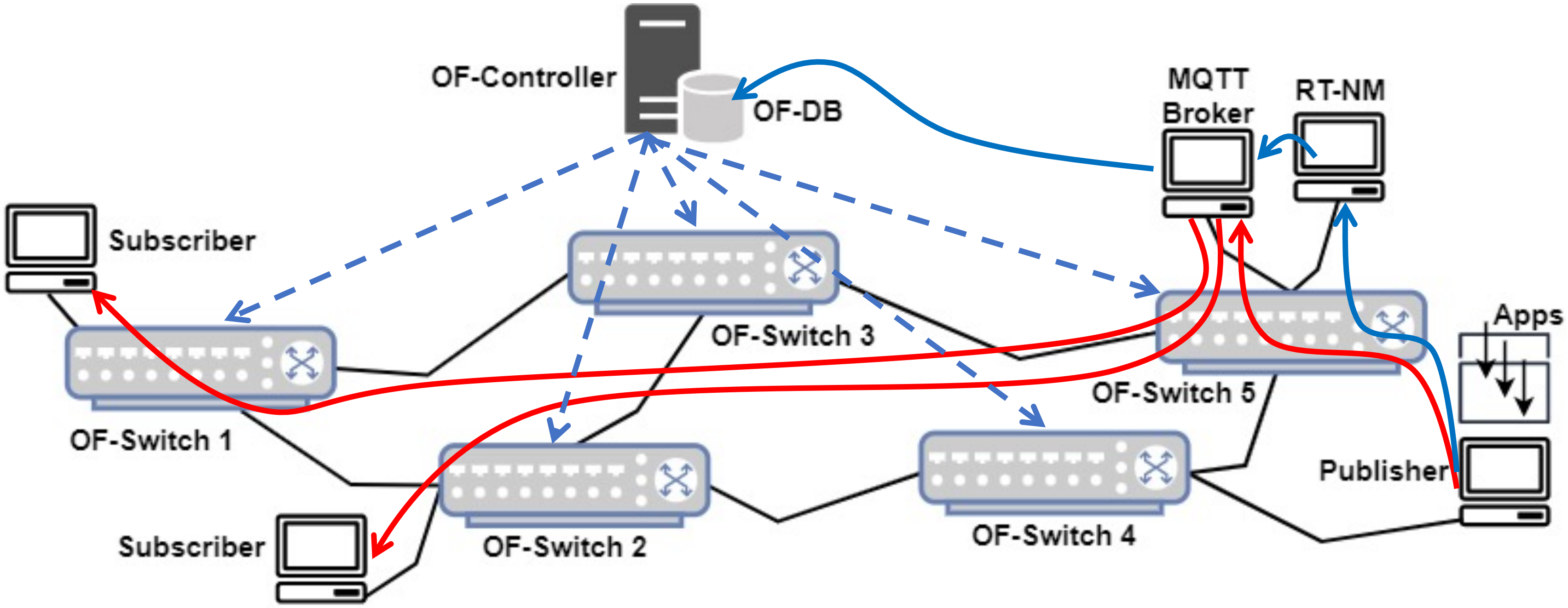
Contribution

- Previous work: RT-MQTT Protocol
  - It **extends MQTT** with real-time services:
    - ✓ Allowing applications to define **real-time requirements**
    - ✓ Translating to **network reservations** using SDN

- Contribution of this work:
  - We first formalize **RT-MQTT system model**
  - We show RT-MQTT worst-case **communication behaviour** is **analysable**
    - ✓ Using fixed-priority non-preemptive scheduling

Network Architecture

- RT-MQTT architecture comprises
  - ✓ IoT nodes
  - ✓ MQTT broker
  - ✓ RT-NM
  - ✓ OF-DB
  - ✓ OF-Controller
  - ✓ OF-Switches

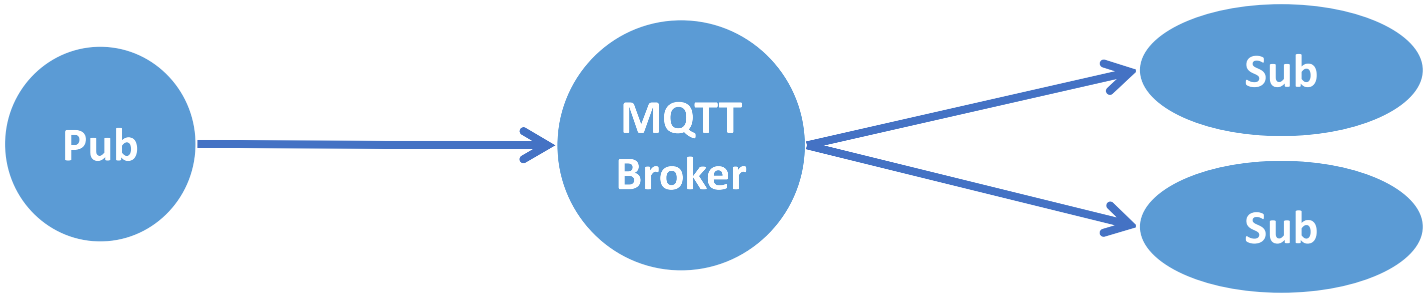


System Model

➢ Message Model

- ❖ RT-MQTT classifies traffic flows in **non-real-time** and **real-time**
  - ✓ Real-time traffic **model**:

$$\Gamma = \{m_i(C_i, PS_i, D_i, T_i, P_i, S_i, DS_i, \mathcal{L}_i, n_i), i = 1 \ldots N\}$$



➢ Scheduling Model:

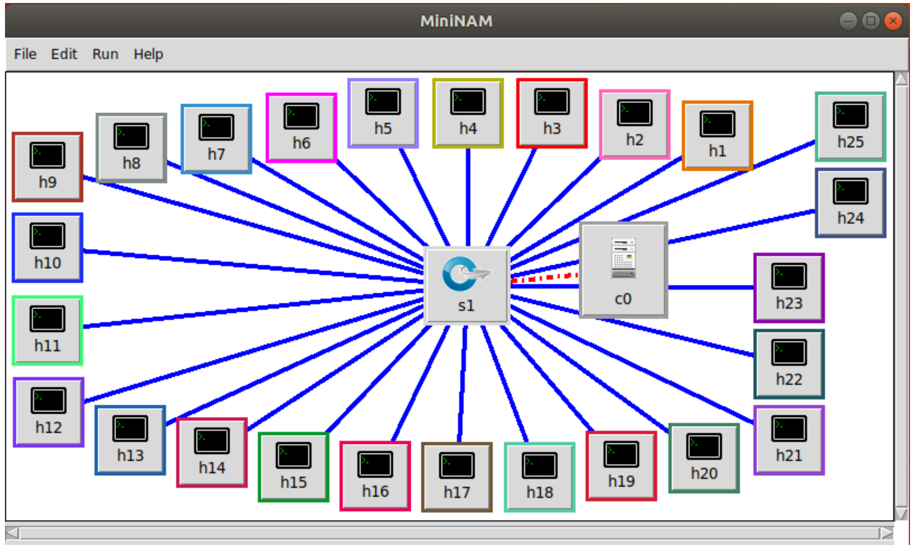
- ❖ A **non-preemptive fixed priority** scheduling with **FIFO** strategy is used
- ❖ The generated delays in the network are categorized in two types:
  - ✓ Blocking delay
  - ✓ Interference delay

We use the **analyses** of **R.I.Davis** and **A.Burns, 2008**

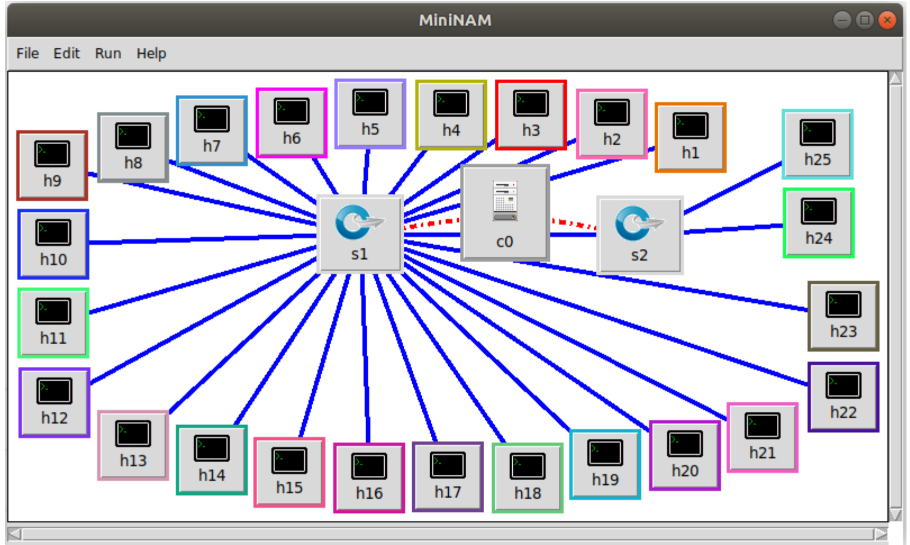
Performance Assessment

➢ Emulation Scenario (Mininet VN emulator):

- Response times are measured for a set of MQTT messages
- **Two network topologies** are considered: **Single-Switch** and **Dual-Switch**
- **Three load-levels** are investigated: **A (5 pubs), B (10 pubs),** and **C (20 pubs)**
- **Heterogeneous data** are exchanged (**real-time** and **non-real-time**)



Single-Switch network topology.



Dual-Switch network topology.

Emulation Setup

- Properties of the **Real-Time** traffic
  - ✓ **Periods** in [2 15] *ms*
  - ✓ **Single packet** messages with **size 1500** bytes

- **Non-real-time** traffic
  - ✓ **TCP** packets using D-ITG (Distributed Internet Traffic Generator)
  - ✓ **Audio/video** streams using VLC media player
  - ✓ **Files** (based on File Transfer Protocol (FTP)) using vsftpd

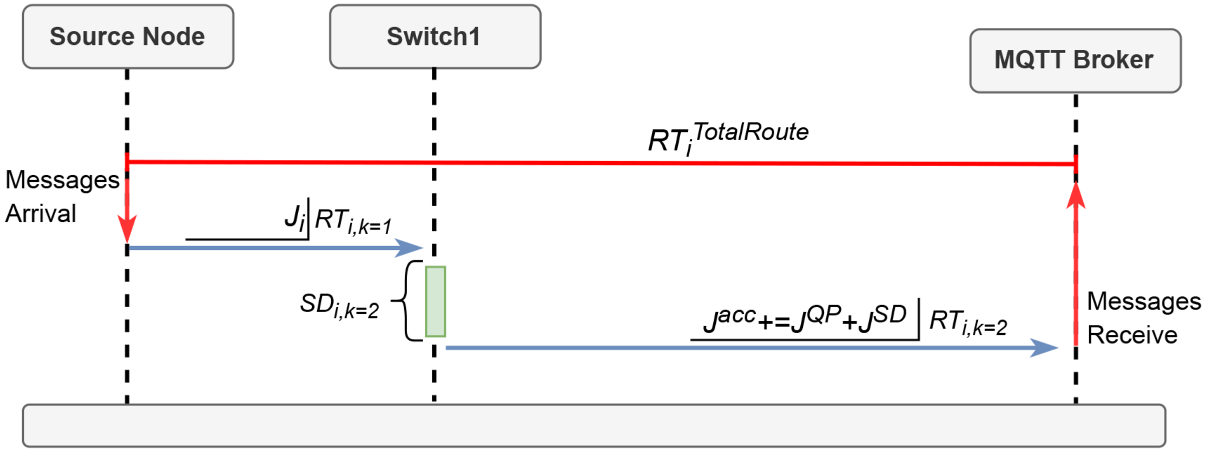
- Each combination was **executed 1000** times
  - ✓ With each publisher generating 100 messages per run

Performance Assessment

❖ **Measurement points** in the experiments are shown for:

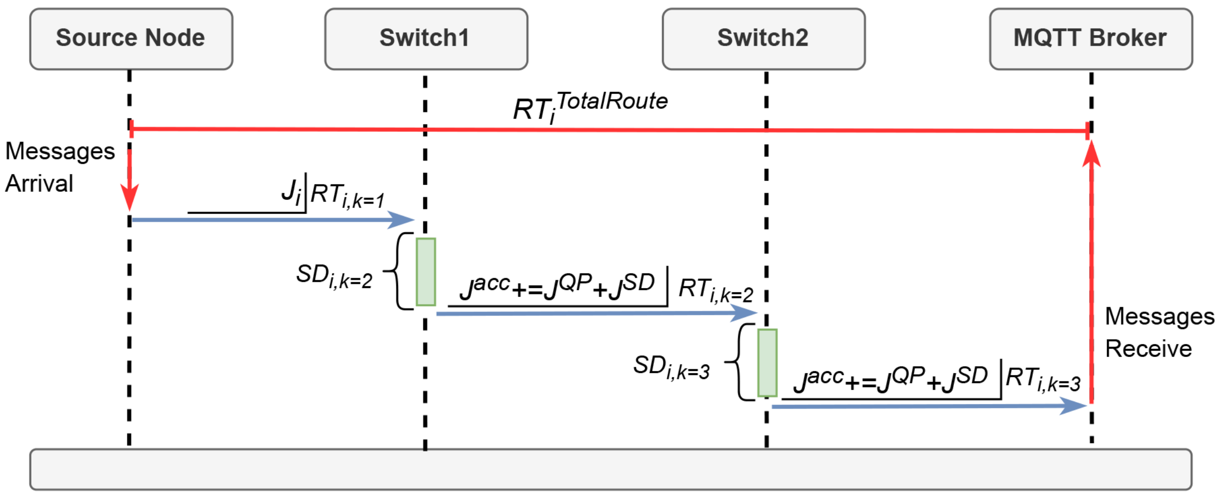
- ✓ Single-Switch
- ✓ Dual-Switch

2 hops



Response time in the **Single-Switch** topology

3 hops



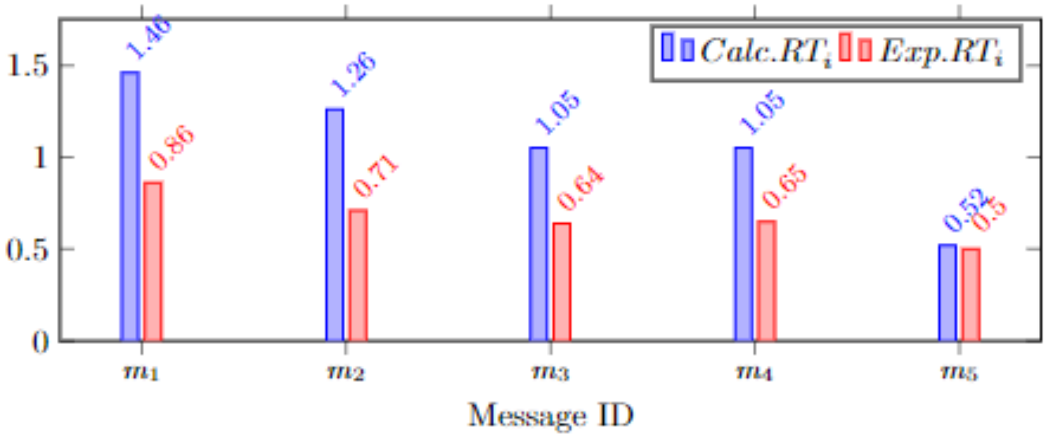
Response time in the **Dual-Switch** topology

Experimental Results

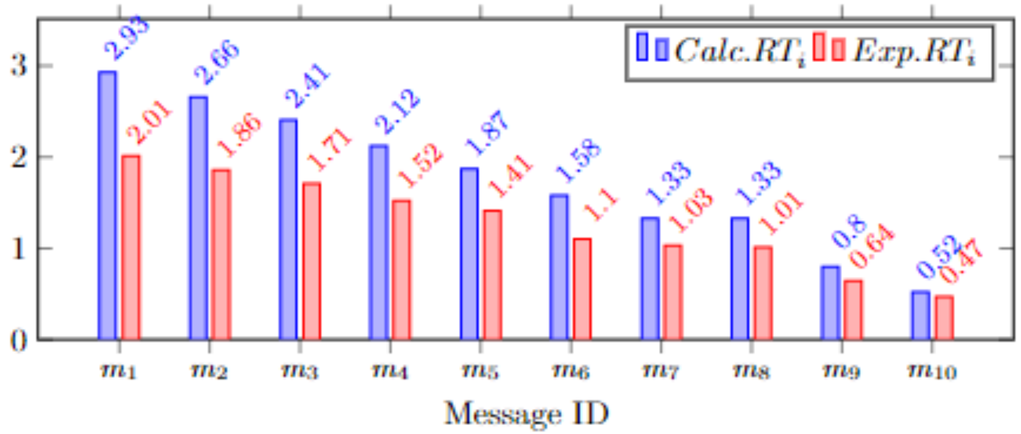
➢ **Analytical (*CalcRT*)** versus **observed (*ExpRT*)** WCRT for **Single-Switch** topology

2 hops, light load (A)

WCRT

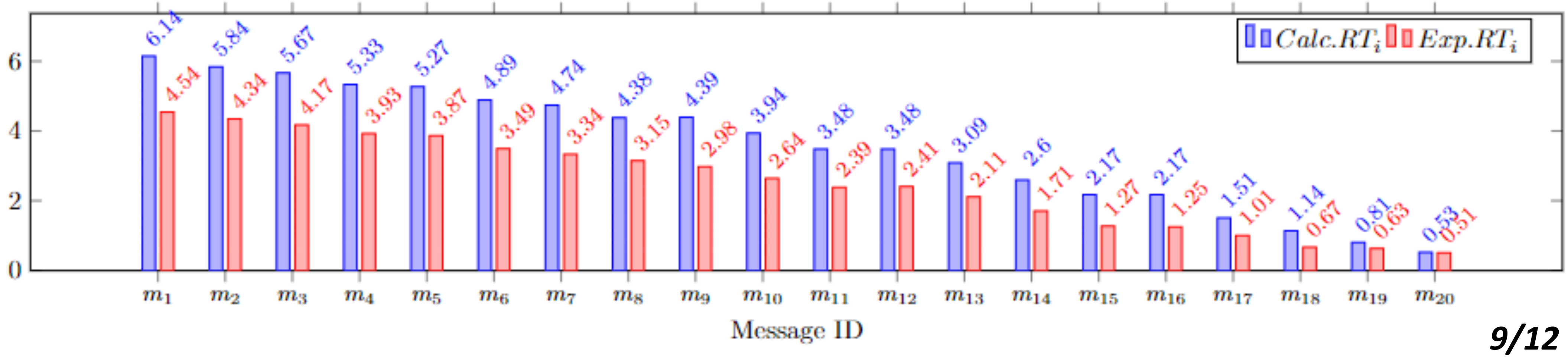


2 hops, mid load (B)



2 hops, high load (C)

WCRT

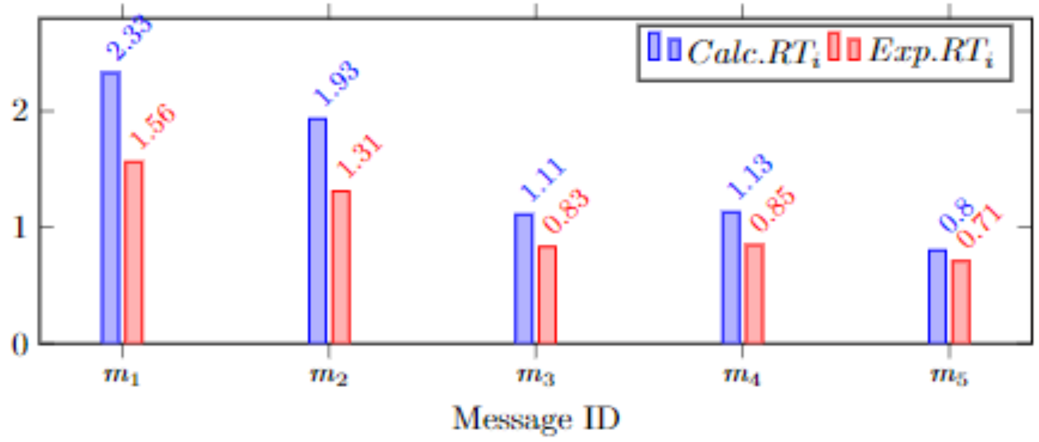


Experimental Results

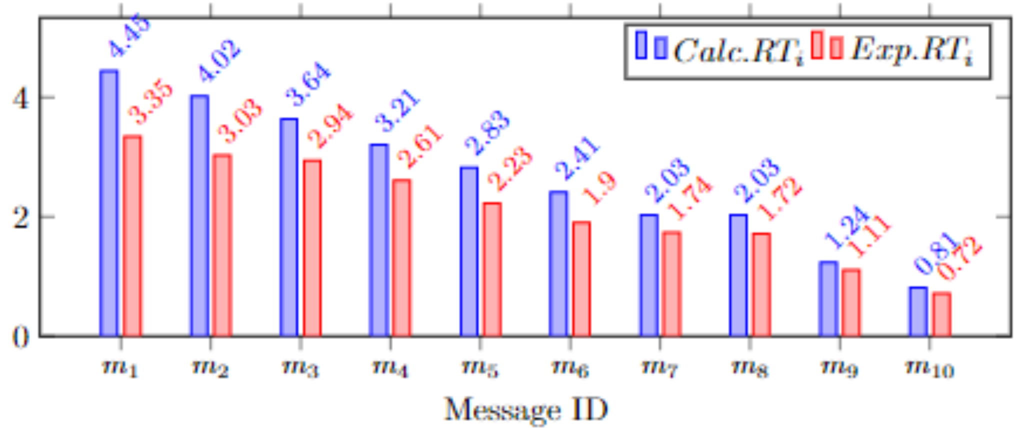
➤ **Analytical (*CalcRT*)** versus **observed (*ExpRT*)** WCRT for **Dual-Switch** topology

3 hops, light load (A)

WCRT

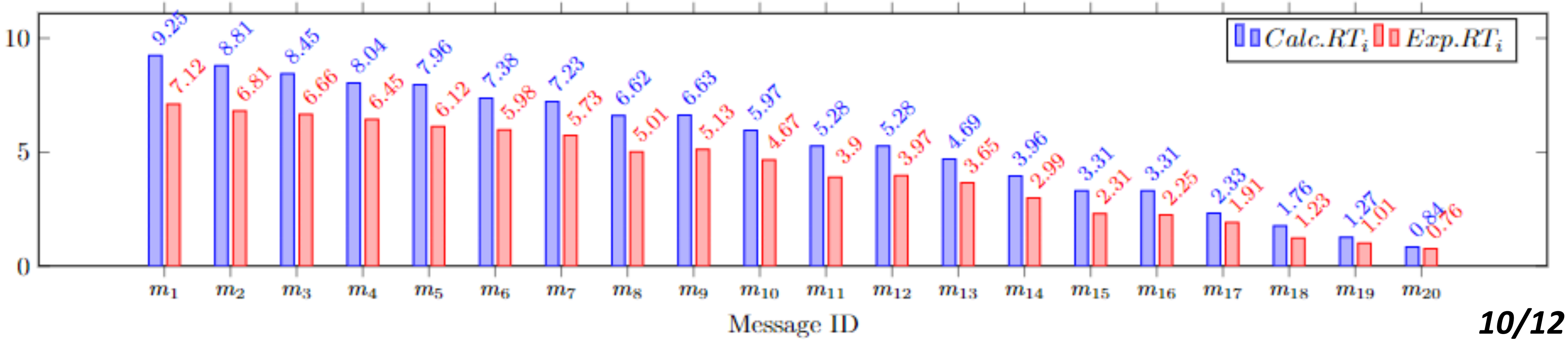


3 hops, mid load (B)



3 hops, high load (C)

WCRT



Experimental Results

- **Comparing Analytical (*CalcRT*)** versus **observed (*ExpRT*)** WCRT

CalcRT / ExpRT

	Light load (A)	Mid load (B)	High load (C)
2 hops (1 switch)	**Max** ratio: **1.69** **Min** ratio: **1.01**	**Max** ratio: 1.45 **Min** ratio: 1.04	**Max** ratio: **1.10** **Min** ratio: 1.03
3 hops (2 switches)	**Max** ratio: 1.49 **Min** ratio: 1.12	**Max** ratio: 1.32 **Min** ratio: 1.11	**Max** ratio: 1.29 **Min** ratio: 1.10

✓ *CalcRT / ExpRT > 1* ➡ Architecture **respects the analysis**

➡ **Pessimism** is tight for high priority messages and generally decreases with load level

Conclusion

➢ **RT-MQTT** is an extension of **MQTT** with real-time services based on **SDN**

❖ An **existing response time analysis** is applied to RT-MQTT:
- ✓ Assumes non-preemptive fixed-priority scheduling of sporadic messages
- ✓ Enforced by the multi-hop **SDN/OpenFlow** switched network
- ✓ Focuses on the **worst-case response time** of the real-time traffic

❖ We carried out **validation experiments** with heterogeneous traffic
- ✓ Used the **Mininet** emulator with two topologies and 3 load levels
- ✓ Generated **heterogeneous traffic** for **1000** times
- ✓ **Observed WCRT** was **always below** Analytical WCRT
  - ✓ Pessimism varied with an **average rate** between 1.11 and 1.36

❖ In future work we will consider the **end-to-end delay** (+broker +end nodes)