Gain More for Less: The Surprising Benefits of QoS Management in Constrained NDN Networks

ACM ICN 2019, Macau

Cenk Gündoğan[1] Jakob Pfender[2] Michael Frey[3]

Thomas C. Schmidt[1] Felix Shzu-Juraschek[3] Matthias Wählisch[4]

[1]HAW Hamburg

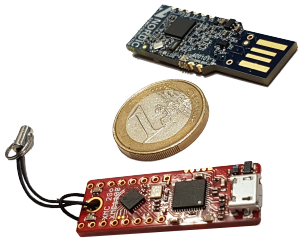
[2]Victoria University of Wellington

[3]Safety IO

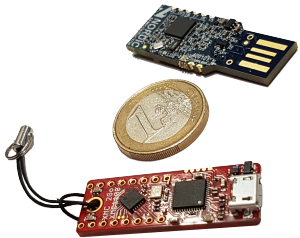
[4]Freie Universität Berlin

Common IoT Deployments

- Always connected, low-cost IoT devices
  - Resource-constrained: MHz CPU, kB RAM/ROM

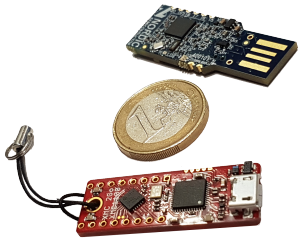


Common IoT Deployments



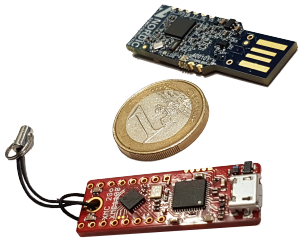
- Always connected, low-cost IoT devices
  - Resource-constrained: MHz CPU, kB RAM/ROM
- Saturated resources impact network performance
  - Local bottlenecks leave the network partially underutilized

Common IoT Deployments



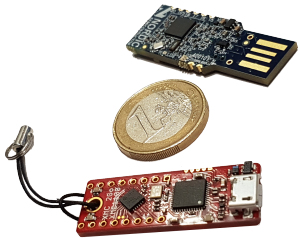
- Always connected, low-cost IoT devices
  - Resource-constrained: MHz CPU, kB RAM/ROM
- Saturated resources impact network performance
  - Local bottlenecks leave the network partially underutilized
- Overprovisioning of resources to meet requirements …

Common IoT Deployments



- Always connected, low-cost IoT devices
  - Resource-constrained: MHz CPU, kB RAM/ROM
- Saturated resources impact network performance
  - Local bottlenecks leave the network partially underutilized
- Overprovisioning of resources to meet requirements … **is infeasible**
  - Device complexity, unit price, and energy consumption increases

Common IoT Deployments



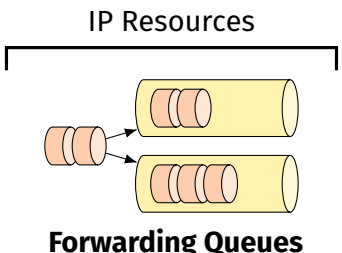
- Always connected, low-cost IoT devices
  - Resource-constrained: MHz CPU, kB RAM/ROM
- Saturated resources impact network performance
  - Local bottlenecks leave the network partially underutilized
- Overprovisioning of resources to meet requirements … **is infeasible**
  - Device complexity, unit price, and energy consumption increases

Quality of Service (QoS) improves resource utilization

Outline

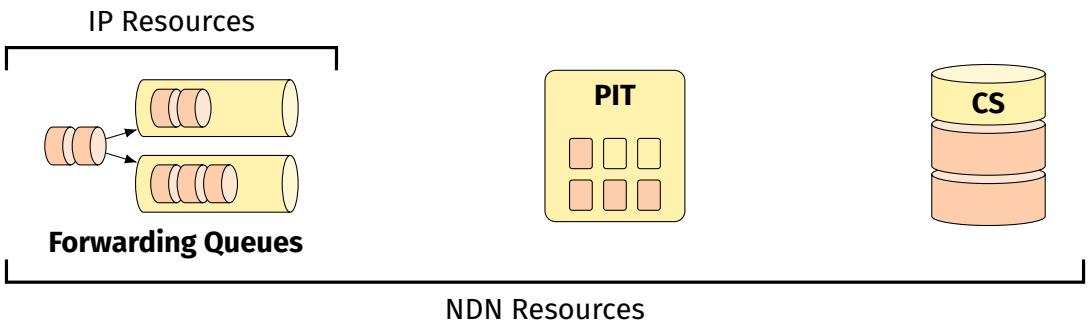
Resources in IP vs. NDN

- Typical IP world resources: link capacities & buffer spaces



Resources in IP vs. NDN

- Typical IP world resources: link capacities & buffer spaces
- CCNx / NDN provides additional resources:
  Pending Interest Table (PIT), Content Store (CS)



Distributed QoS Management

QoS Building Blocks

1. Traffic classification

2. QoS treatments

QoS Building Blocks

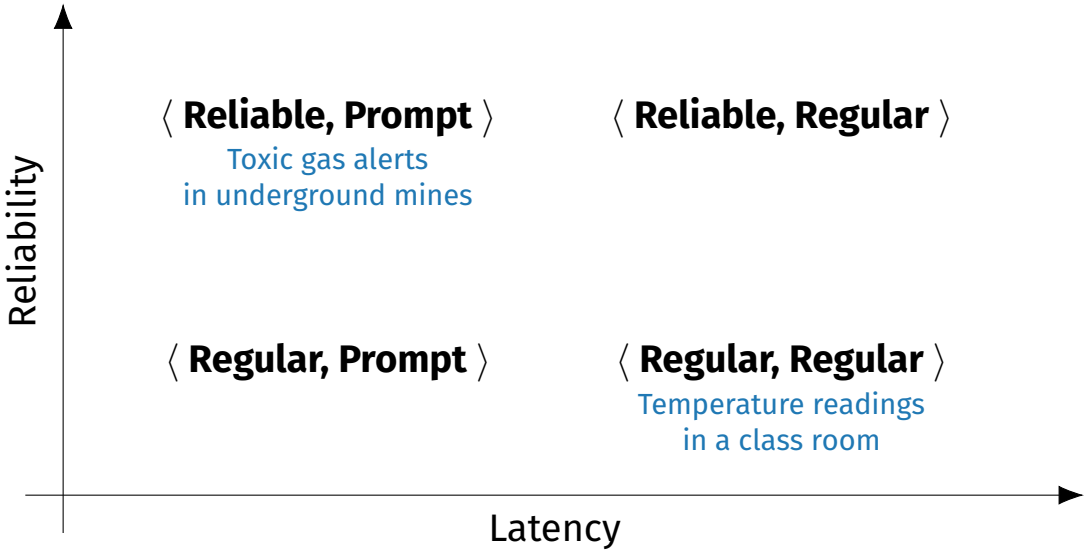
1. Traffic classification
   - *Longest prefix match (LPM)* with pre-defined ***name***↔***priority*** table
   - Alternatively: draft-moiseenko-icnrg-flowclass, I. Moiseenko and D. Oran
2. QoS treatments

QoS Building Blocks

1. Traffic classification
   - *Longest prefix match (LPM)* with pre-defined ***name*↔*priority*** table
   - Alternatively: draft-moiseenko-icnrg-flowclass, I. Moiseenko and D. Oran

2. QoS treatments ⇐ **focus of this talk**
   - Define quality dimensions
   - Specify resource management rules

Quality Dimensions



Resource Management Rules

1. Isolated Decisions

Forwarding Queue
Delay *regular* traffic

Pending Interest Table
Evict *regular* for *prompt*

Content Store
Evict *regular* for *reliable*

2. Resource Correlations

CS—PIT Correlation
Prompt Data meets no PI
⇒ cached with priority

CS—Forward. Correlation
Prompt Data dropped
⇒ cached with priority

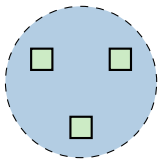
3. Distributed Coordination

PIT Coherence
Same config. at all nodes
⇒ *Regular* < *Reliable* < *Prompt*

CS Efficiency
Same config. at all nodes
⇒ *Regular* < *Prompt* < *Reliable*

Resource Management Rules

1. Isolated Decisions



2. Resource Correlations

3. Distributed Coordination

Forwarding Queue
Delay *regular* traffic

Pending Interest Table
Evict *regular* for *prompt*

Content Store
Evict *regular* for *reliable*

CS—PIT Correlation
Prompt Data meets no PI
⇒ cached with priority

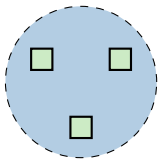
CS—Forward. Correlation
Prompt Data dropped
⇒ cached with priority

PIT Coherence
Same config. at all nodes
⇒ *Regular* < *Reliable* < *Prompt*

CS Efficiency
Same config. at all nodes
⇒ *Regular* < *Prompt* < *Reliable*

Resource Management Rules

1. Isolated Decisions

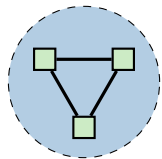


Forwarding Queue
Delay *regular* traffic

Pending Interest Table
Evict *regular* for *prompt*

Content Store
Evict *regular* for *reliable*

2. Resource Correlations



CS—PIT Correlation
Prompt Data meets no PI
⇒ cached with priority

CS—Forward. Correlation
Prompt Data dropped
⇒ cached with priority

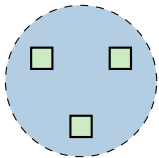
3. Distributed Coordination

PIT Coherence
Same config. at all nodes
⇒ *Regular* < *Reliable* < *Prompt*

CS Efficiency
Same config. at all nodes
⇒ *Regular* < *Prompt* < *Reliable*

Resource Management Rules

1. Isolated Decisions

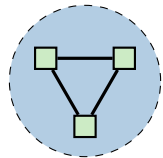


Forwarding Queue
Delay *regular* traffic

Pending Interest Table
Evict *regular* for *prompt*

Content Store
Evict *regular* for *reliable*

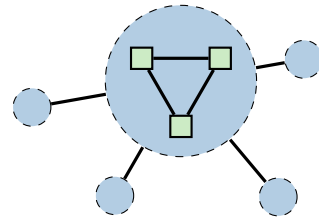
2. Resource Correlations



CS—PIT Correlation
Prompt Data meets no PI
$\Rightarrow$ cached with priority

CS—Forward. Correlation
Prompt Data dropped
$\Rightarrow$ cached with priority

3. Distributed Coordination



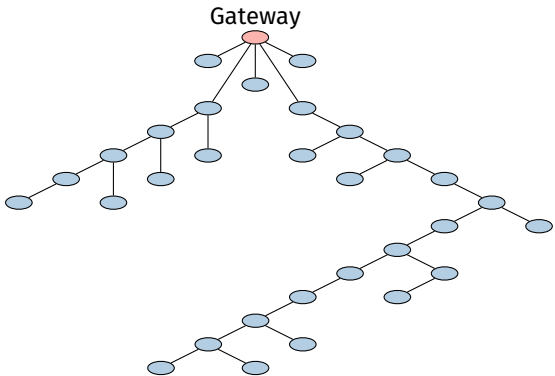
PIT Coherence
Same config. at all nodes
$\Rightarrow$ *Regular* $<$ *Reliable* $<$ *Prompt*

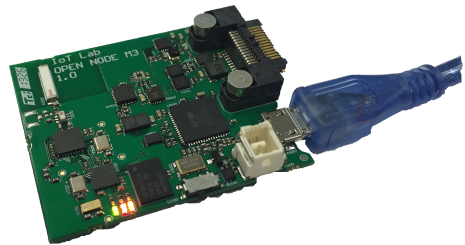
CS Efficiency
Same config. at all nodes
$\Rightarrow$ *Regular* $<$ *Prompt* $<$ *Reliable*

Experimental Evaluation

Experimental Evaluation Setup

Hardware: M3 Node in IoT Lab testbed
Software: RIOT with CCN-lite
Network: Multi-hop topology with 31 nodes





M3 Node (ARM Cortex-M3)
64 kB RAM / 512 kB ROM
802.15.4 radio transceiver

Scenario Descriptions

Mixed Sensors and Actuators

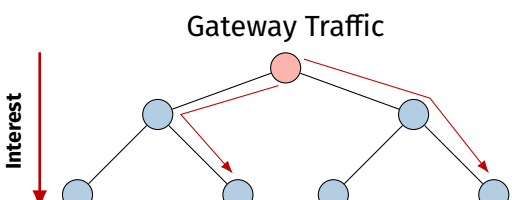
Sensing and Lighting Control

Scenario Descriptions

Mixed Sensors and Actuators

- Gateway requests **device-specific** temperature readings every **10 s** $\pm$ **2 s**

Sensing and Lighting Control

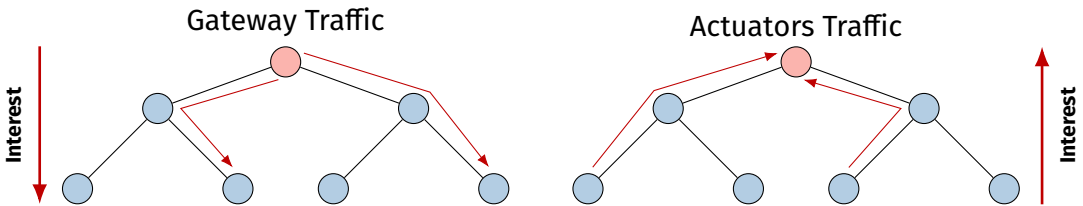


Scenario Descriptions

Mixed Sensors and Actuators

- Gateway requests **device-specific** temperature readings every **10 s** $\pm$ **2 s**
- Actuators request **device-specific** state from gateway every **5 s** $\pm$ **1 s**

Sensing and Lighting Control



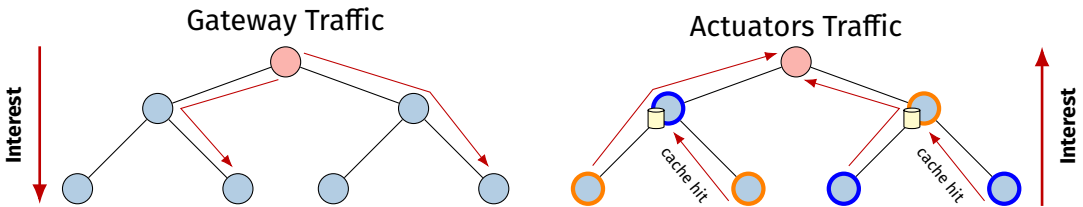
Scenario Descriptions

Mixed Sensors and Actuators

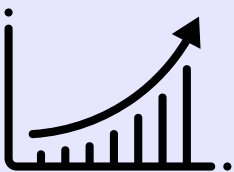
- Gateway requests **device-specific** temperature readings every **10 s** $\pm$ **2 s**
- Actuators request **device-specific** state from gateway every **5 s** $\pm$ **1 s**

Sensing and Lighting Control

- Actuators request **group-specific** instructions from gateway every **5 s** $\pm$ **1 s**

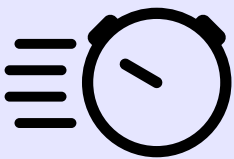


Evaluation Metrics



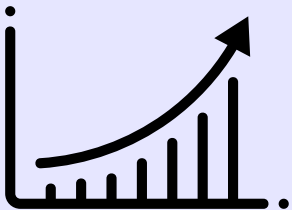
Success

Throughput

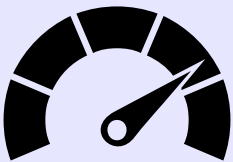


Latency

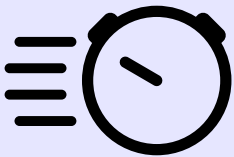
Evaluation Metrics: Success Rates



Success

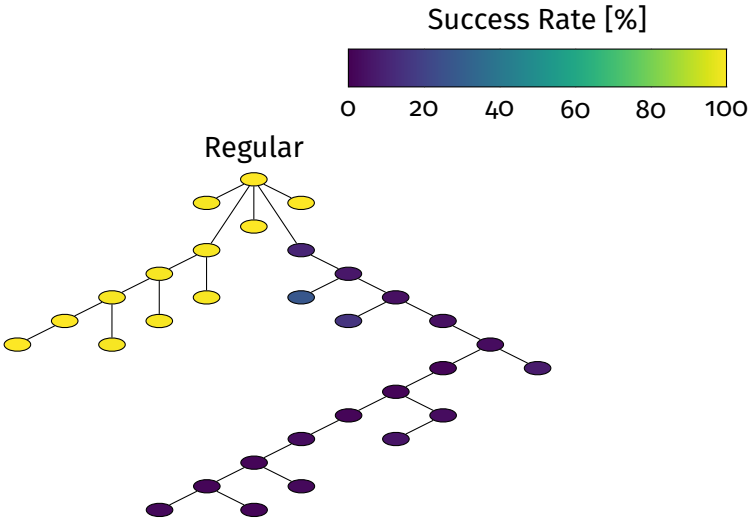


Throughput

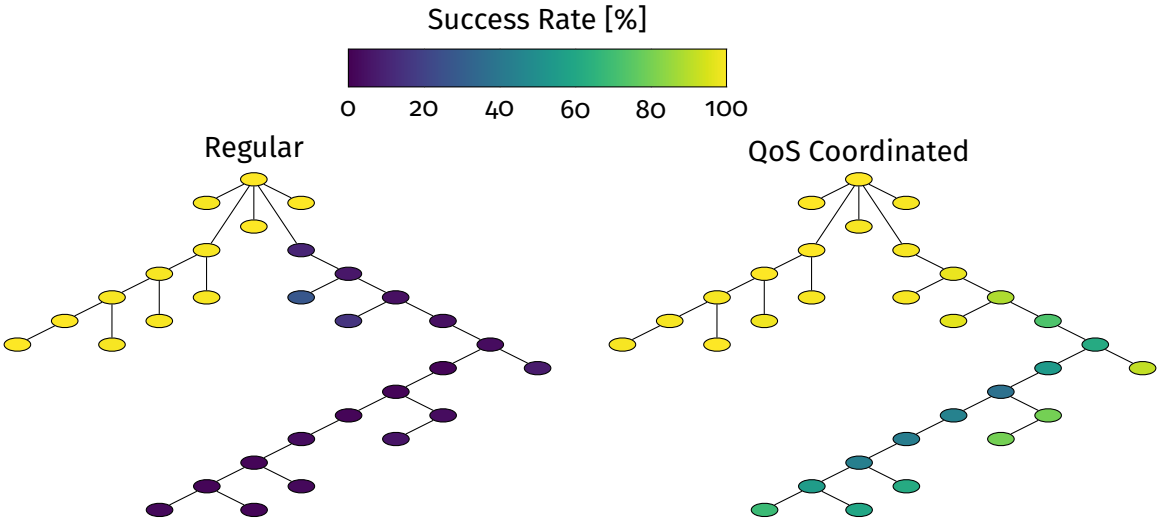


Latency

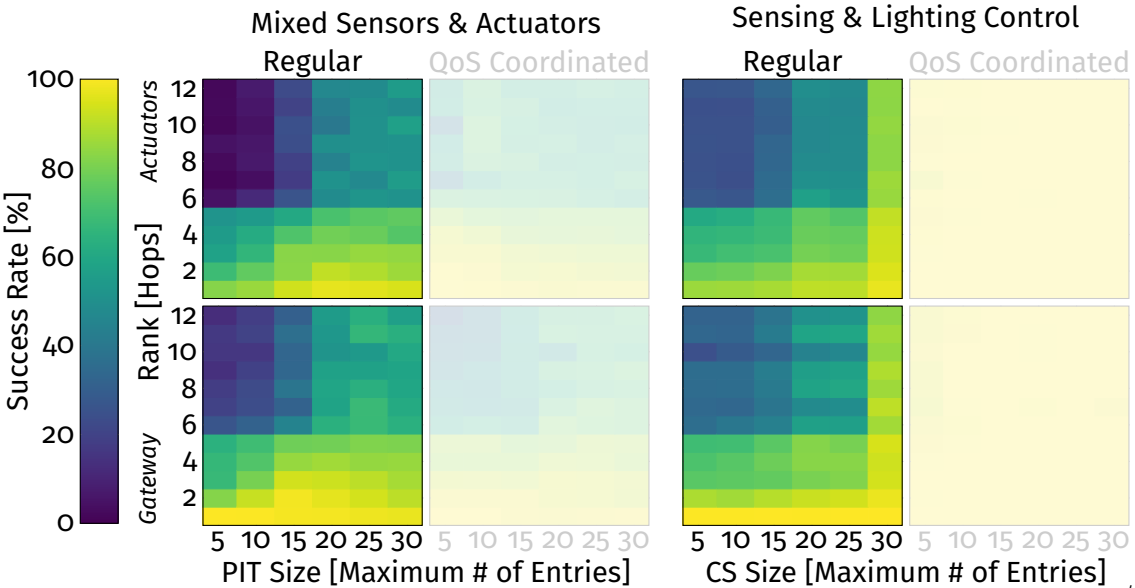
Nodal Success Rates for Actuators Traffic



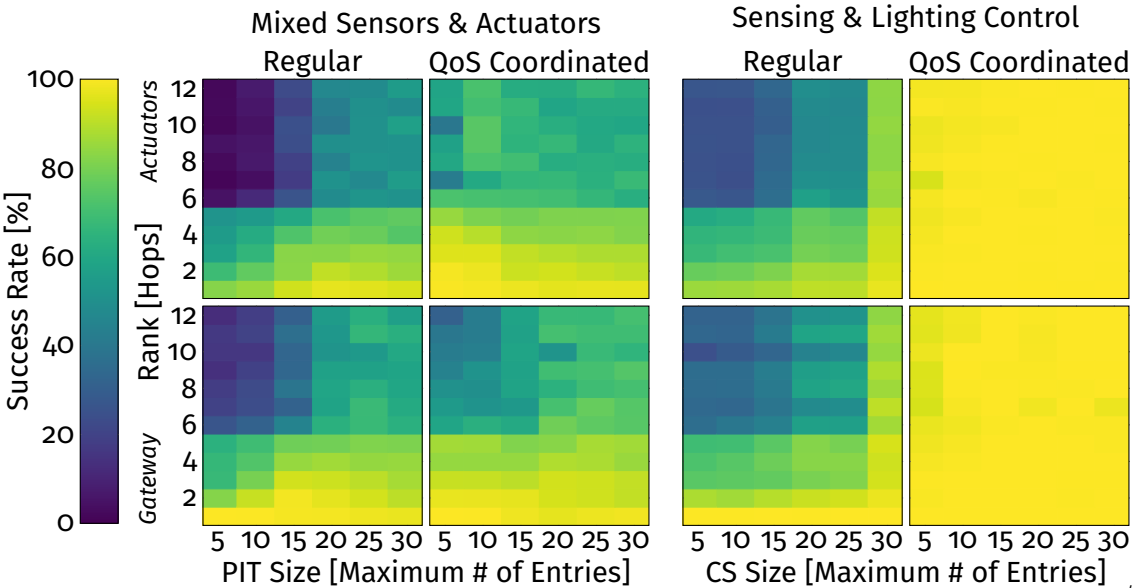
Nodal Success Rates for Actuators Traffic



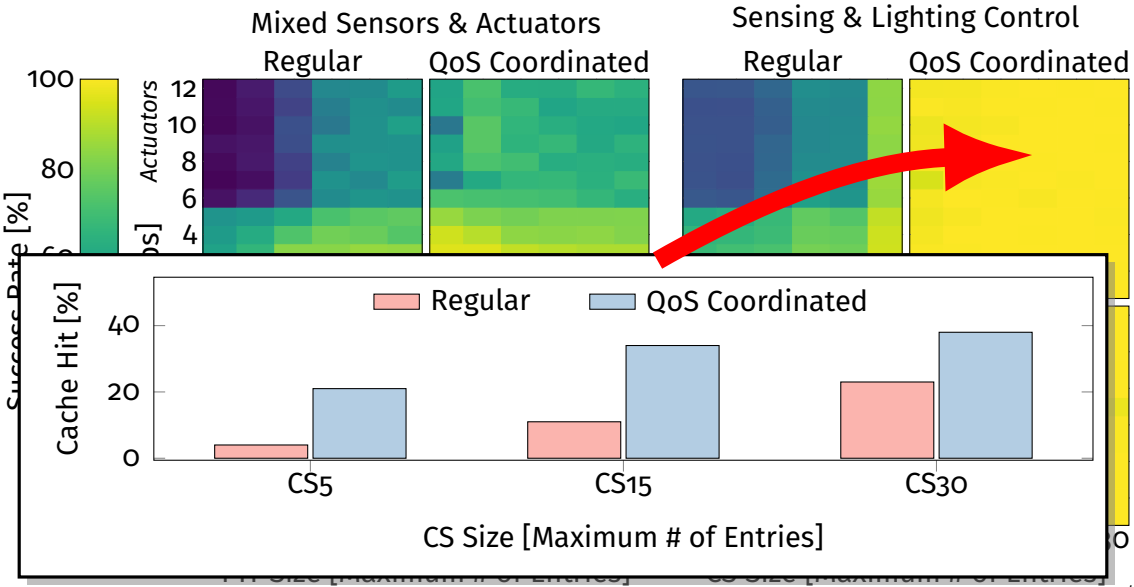
Overall Success Rates



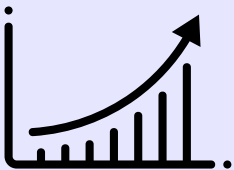
Overall Success Rates



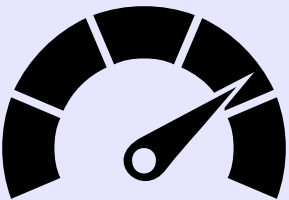
Overall Success Rates



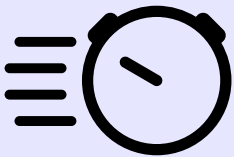
Evaluation Metrics: Throughput Evolution



Success

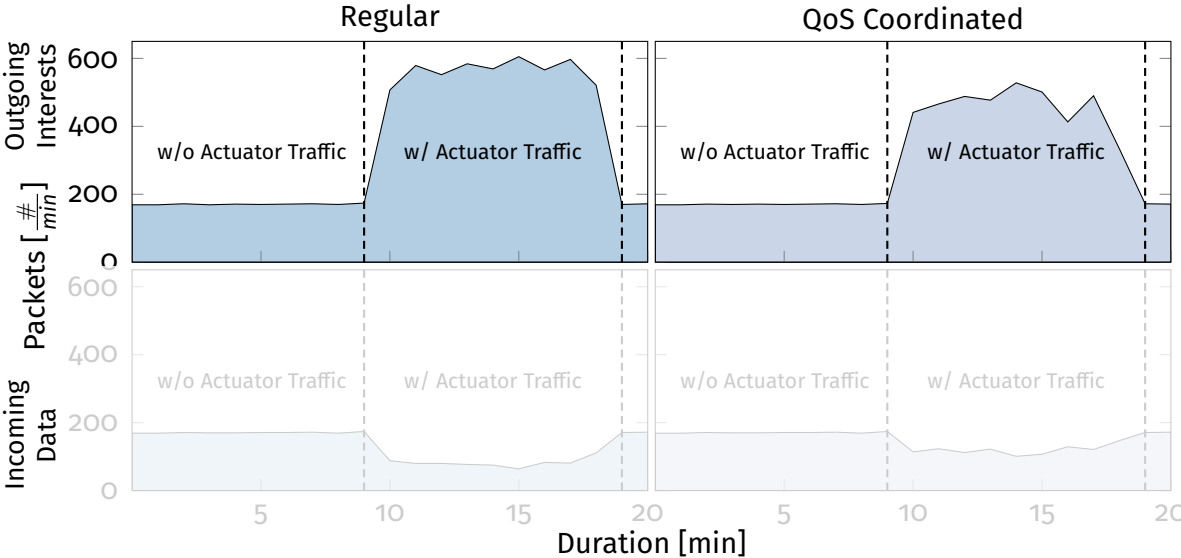


Throughput

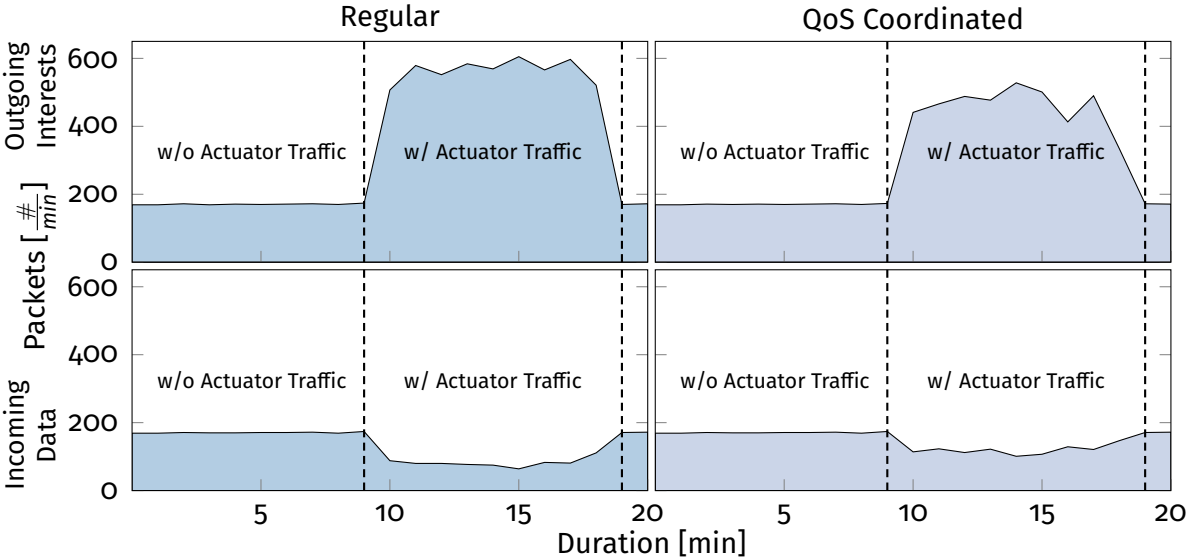


Latency

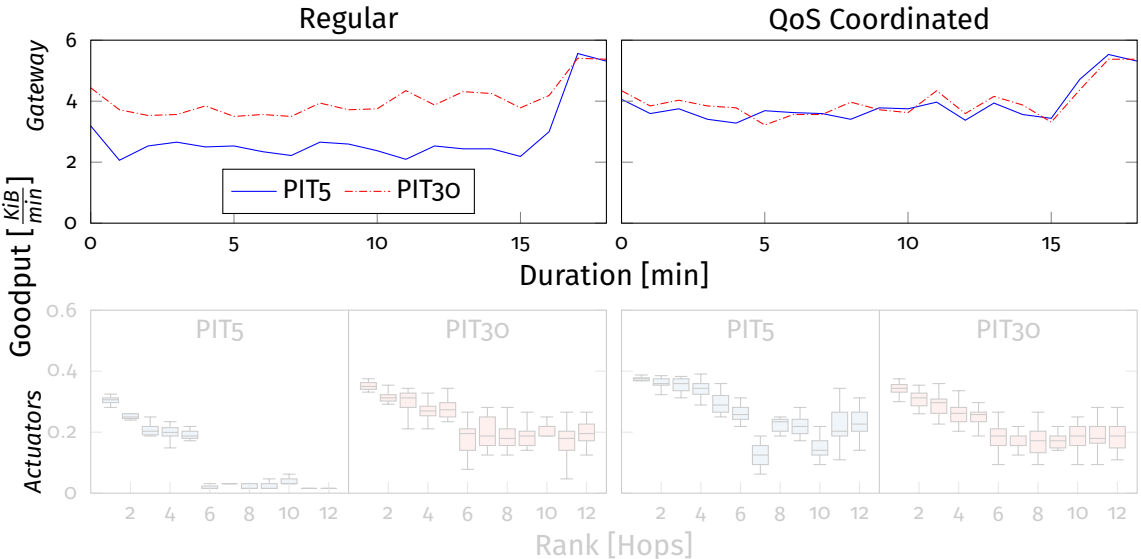
Throughput Evolution for Unprioritized Traffic



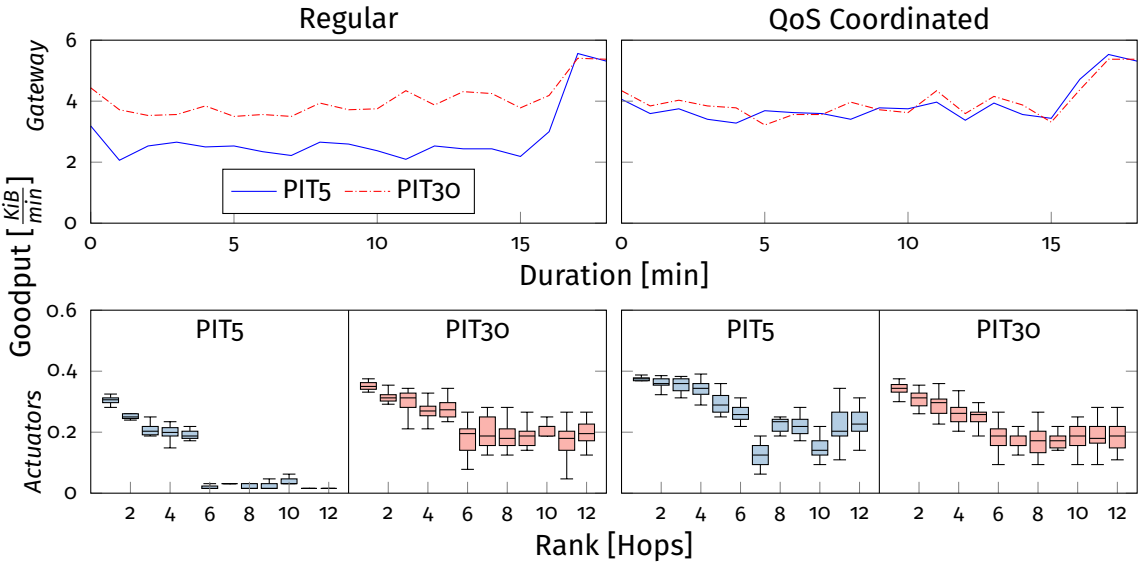
Throughput Evolution for Unprioritized Traffic



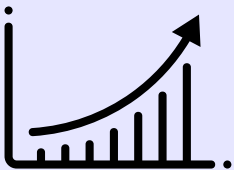
Goodput Evolution



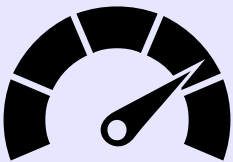
Goodput Evolution



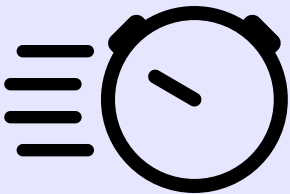
Evaluation Metrics: Completion Time



Success

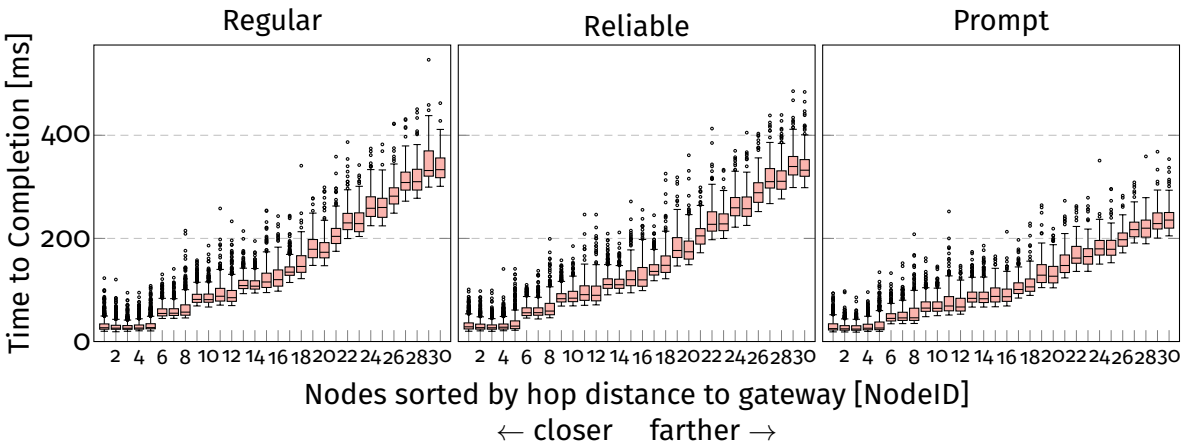


Throughput



Latency

Nodal Completion Time for Actuators Traffic



Conclusion & Outlook

Takeaways

- PIT and cache space have prevailing effects on overall network performance
- QoS in NDN is not confined to simple resource trading
- Treating Interest as well as Data messages allows for resource correlations
- Unprioritized traffic benefits from resource coordination

Next Steps

- Investigate further correlations between PIT, CS, and buffer spaces
- Elaborate on the choice of quality dimensions and service levels