Freie Universität Berlin

HAW HAMBURG

NDN, CoAP, and MQTT: A Comparative Measurement Study in the IoT

ACM ICN 2018, Boston

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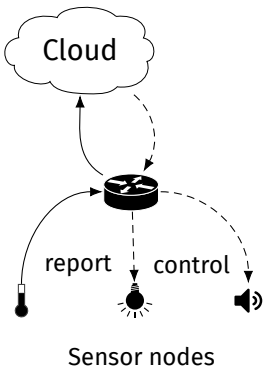
Hauke Petersen[2] Thomas C. Schmidt[1] Matthias Wählisch[2]

[1]HAW Hamburg

[2]Freie Universität Berlin

Common IoT Communication

- Sensors and actuators connect to clouds
  - Today mainly based on MQTT



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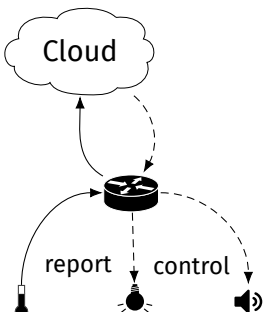

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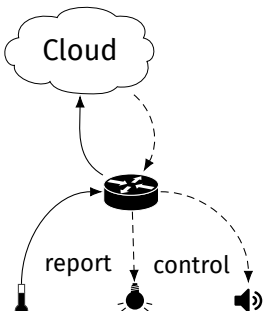

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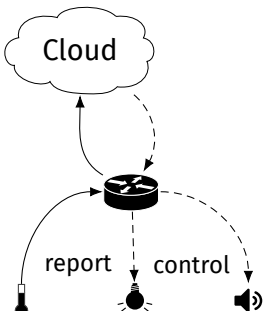
- ICN
  - Promising candidate for future IoT
  - Intensifying attention since 2014



Research Question

How do these protocols perform and
which is most appropriate for the IoT?

Outline

Protocol Overview

Metrics & Experiment Setup

Evaluation
- Single-hop: Push vs. Pull Protocols
- Multi-hop: Reliability and Protocol Performance

Conclusion & Outlook

CoAP

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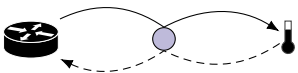

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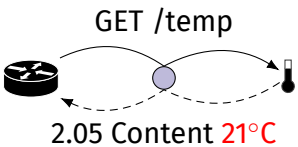

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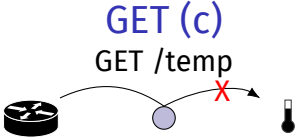

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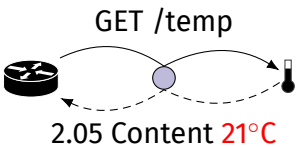

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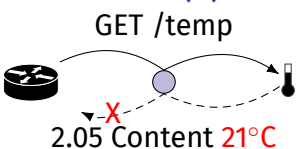

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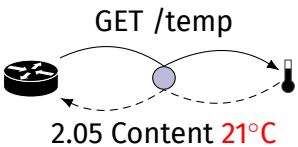

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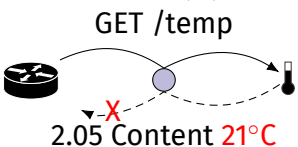

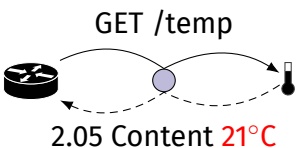

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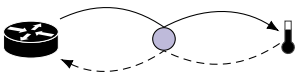

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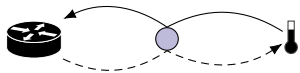

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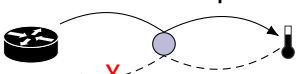

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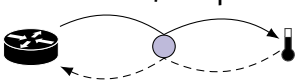

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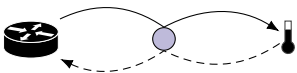

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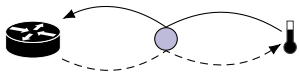

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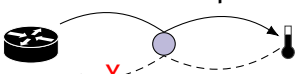

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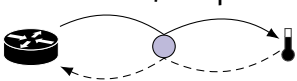

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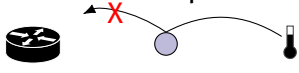

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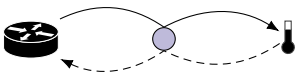

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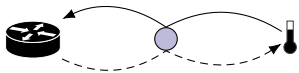

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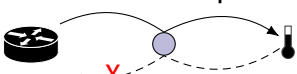

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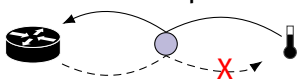

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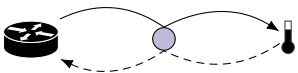

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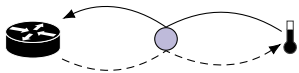

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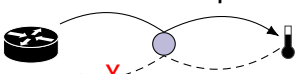

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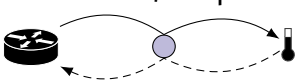

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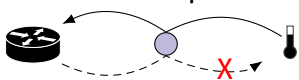

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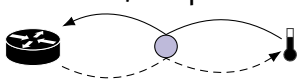

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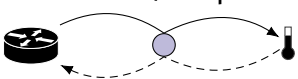

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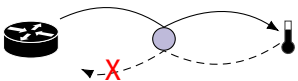

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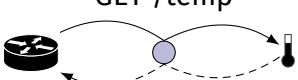

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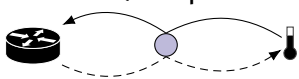

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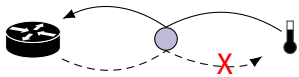

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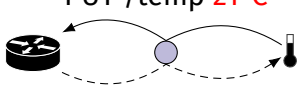

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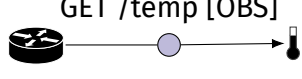

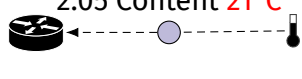

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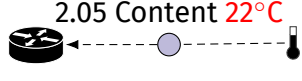

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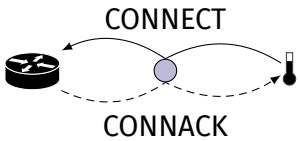
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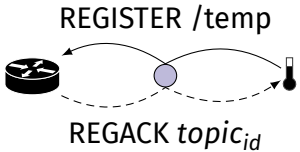
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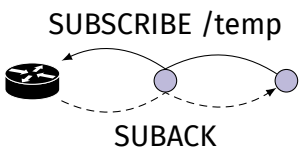
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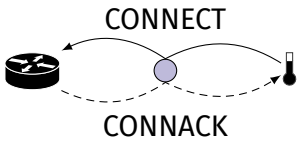

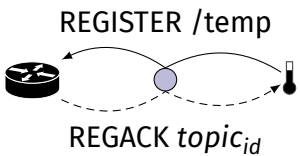

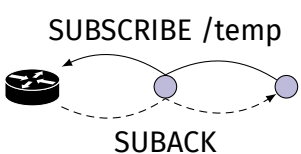

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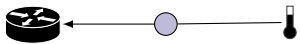

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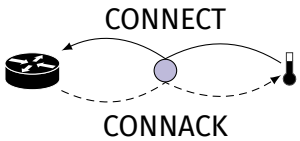

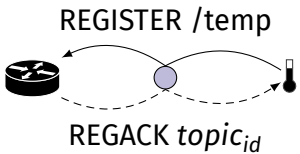

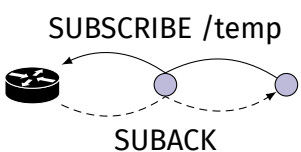

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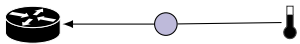

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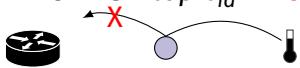

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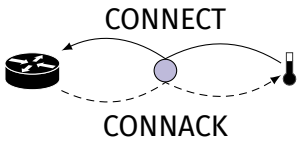

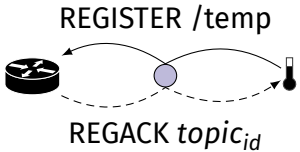

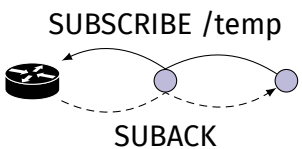

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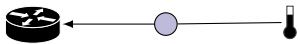

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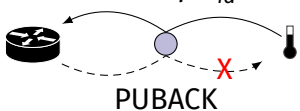

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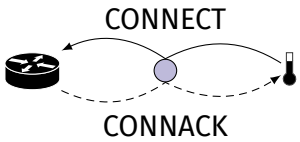
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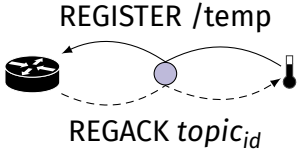
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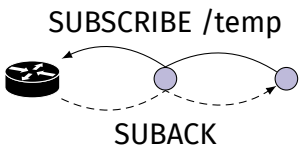
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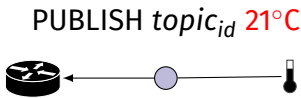
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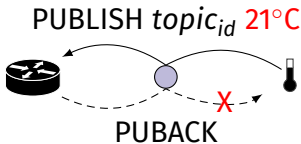
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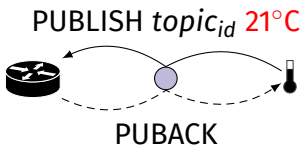
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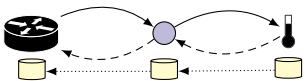

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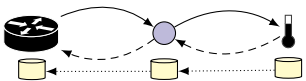

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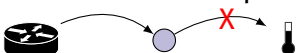

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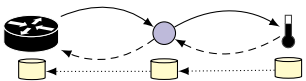

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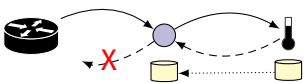

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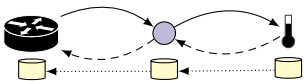

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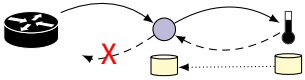

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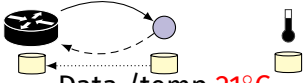

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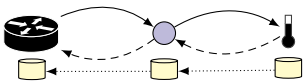

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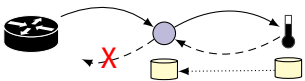

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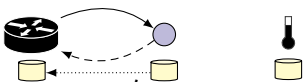

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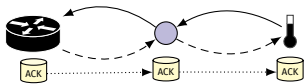

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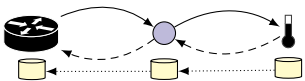

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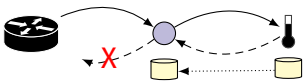

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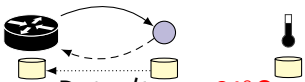

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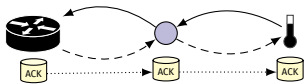

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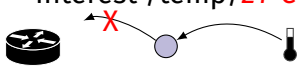

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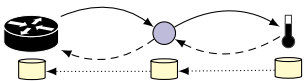

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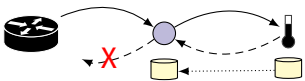

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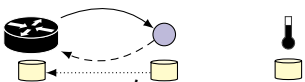

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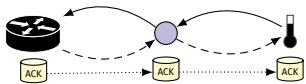

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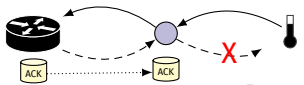

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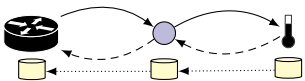

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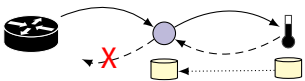

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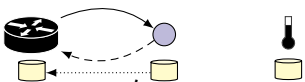

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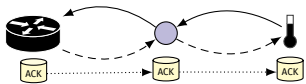

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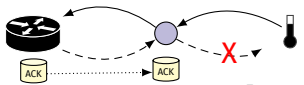

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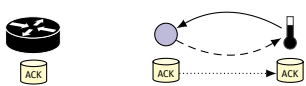

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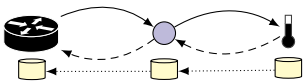

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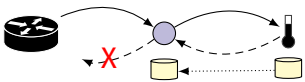

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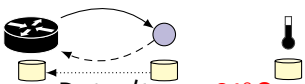

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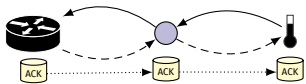

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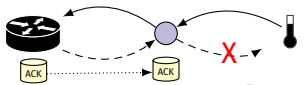

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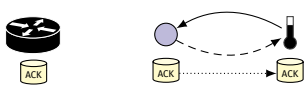

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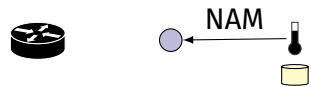

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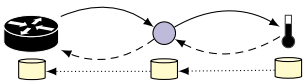

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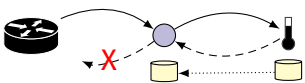

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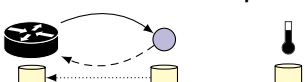

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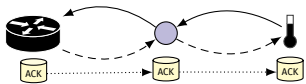

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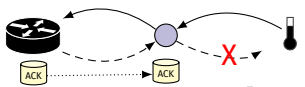

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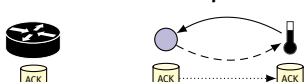

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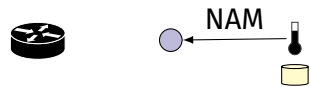

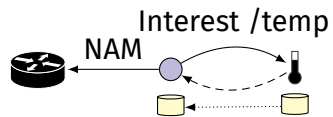

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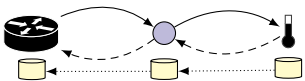

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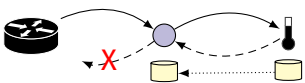
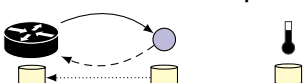


Data /temp 21°C

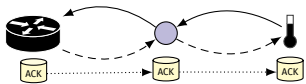
Interest /temp



Data /temp 21°C

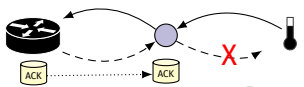
I-Not

Interest /temp/*21°C*



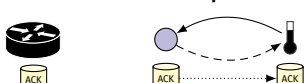
Data /temp/*21°C* [ACK]

Interest /temp/*21°C*



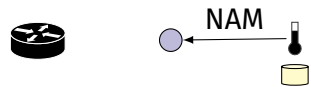
Data /temp/*21°C* [ACK]

Interest /temp/*21°C*

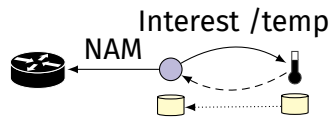


Data /temp/*21°C* [ACK]

HoPP

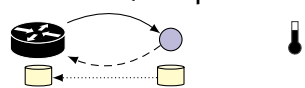


Interest /temp



Data /temp 21°C

Interest /temp



Data /temp 21°C

Properties at a Glance

	Current IoT Protocols				**ICN Protocols**		
	CoAP			MQTT-SN	NDN	I-Not	HoPP
	GET	PUT	OBS				
Transport	UDP	UDP	UDP	UDP	—	—	—
Push	✘	✓	✓	✓	✘	✓	✘
Pull	✓	✘	✘	✘	✓	✘	✓
Pub/Sub	✘	✘	✓	✓	✘	✘	✓
Flow Control	✘	✘	✘	✘	✓	✘	✓
Reliability	(c)	(c)	✘	(Q1)	✓	✓	✓

Experimentation

Implementations

- CoAP: `gcoap`
- MQTT-SN: `asymcute`
- On top of UDP/IPv6

- NDN v0.2
- HoPP & I-Not (extensions)
- On top of link layer

Metrics

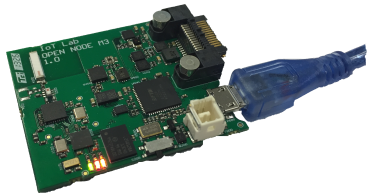
- Network stack sizes
- Time to content arrival
- Link stress
- Goodput
- Network utilization (control vs data plane)
- Energy consumption
- Security overhead

Metrics

- Network stack sizes
- Time to content arrival
- Link stress
- Goodput
- *Network utilization (control vs data plane)*
- *Energy consumption*
- *Security overhead*

Experiment Setup

IoT-Lab Testbed
ARM Cortex-M3
64 kB RAM & 512 kB ROM
IEEE 802.15.4 radio
CSMA/CA



Retransmissions:
Link layer: 4×2–10 ms
Network layer: 4×2 s

Single-hop

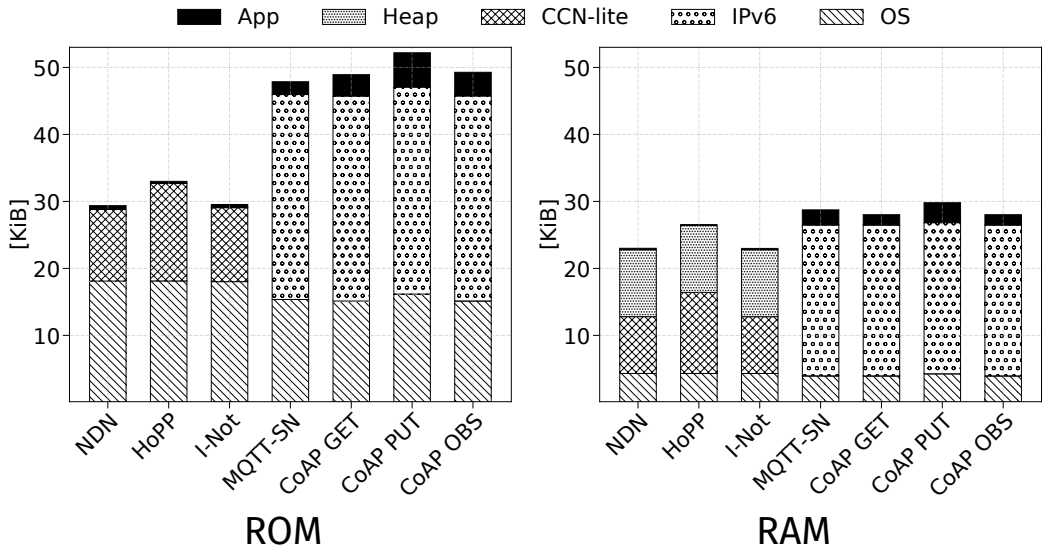
- 1 gateway + 1 IoT node

Multi-hop

- 1 gateway + 50 IoT nodes
- Max. hop distance: 6

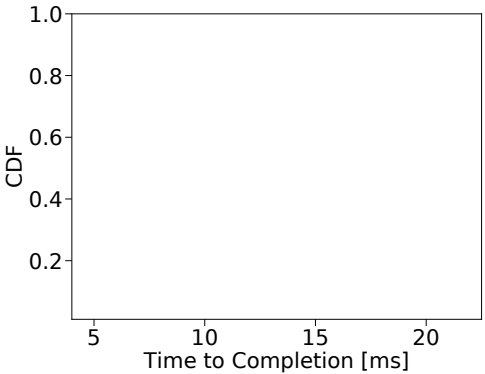
Evaluation

Network Stack Sizes

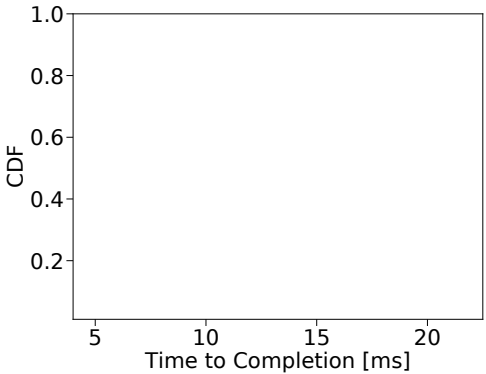


Single-hop: Push vs. Pull

Time to content arrival for scheduled publishing every 50 ms



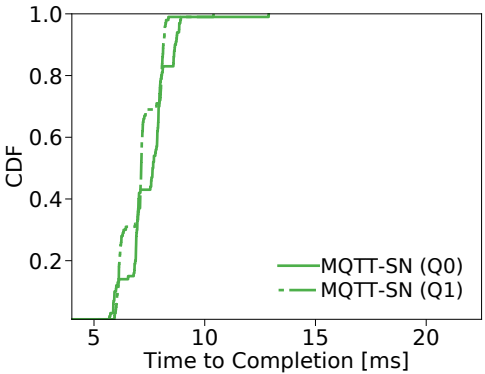
Push protocols



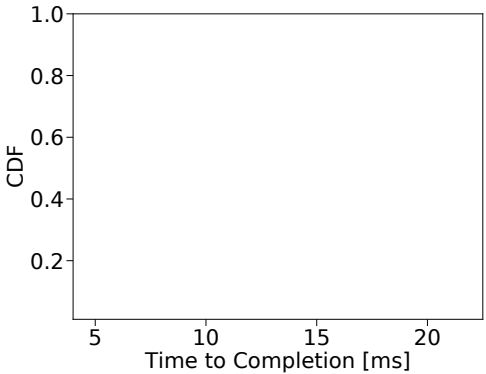
Pull protocols

Single-hop: Push vs. Pull

Time to content arrival for scheduled publishing every 50 ms



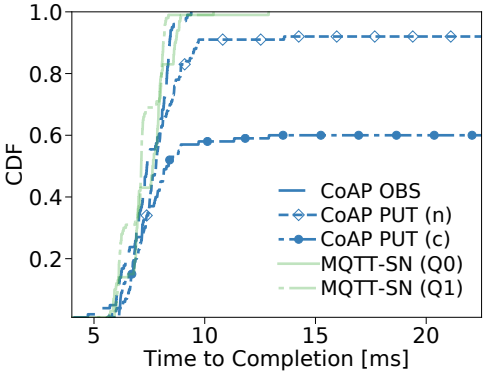
Push protocols



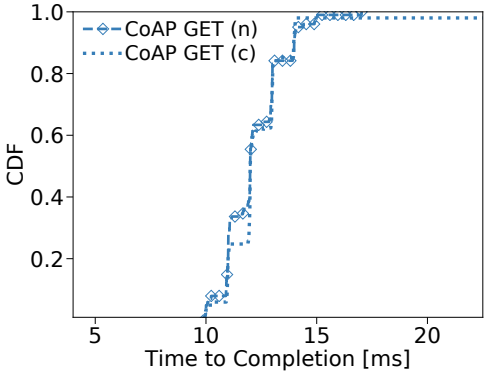
Pull protocols

Single-hop: Push vs. Pull

Time to content arrival for scheduled publishing every 50 ms



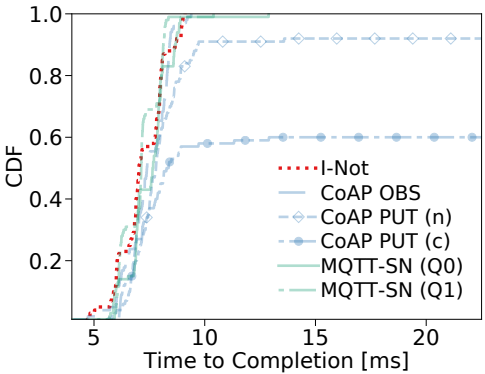
Push protocols



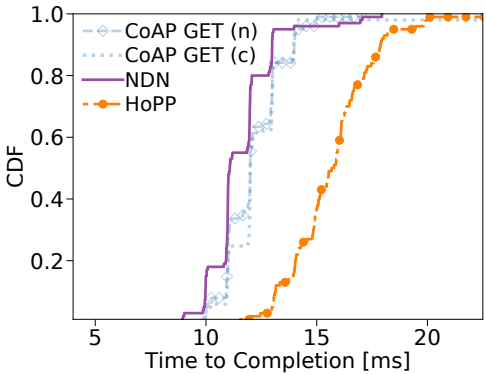
Pull protocols

Single-hop: Push vs. Pull

Time to content arrival for scheduled publishing every 50 ms



Push protocols



Pull protocols

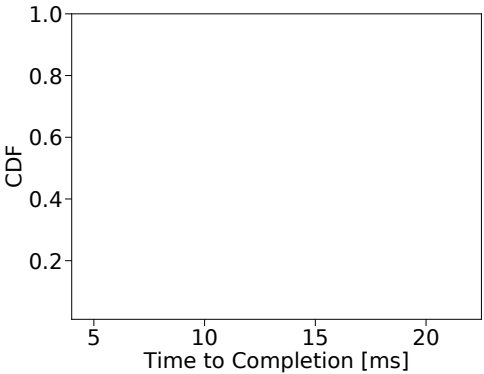
Single-hop: Push vs. Pull

Takeaways

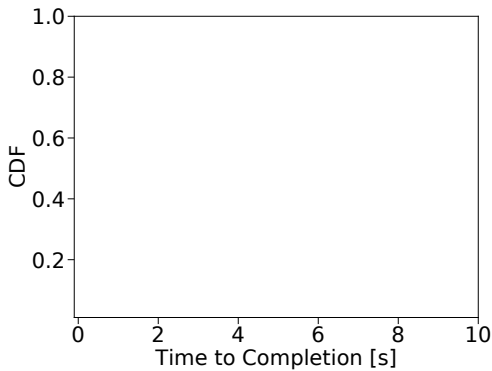
- Without network layer repair
  - Push protocols complete below 10 ms
  - Pull protocols double completion time
- With network layer repair
  - Reliability layer increases completion time to seconds
  - Retransmissions may induce additional link stress

Single-hop: Push vs. Pull

Time to content arrival for unscheduled publishing every [1 ... 3] s, content request every 1 s



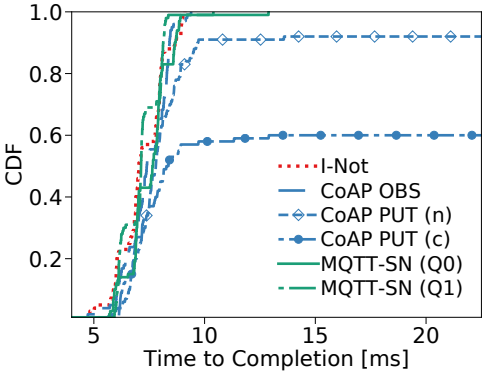
Push protocols



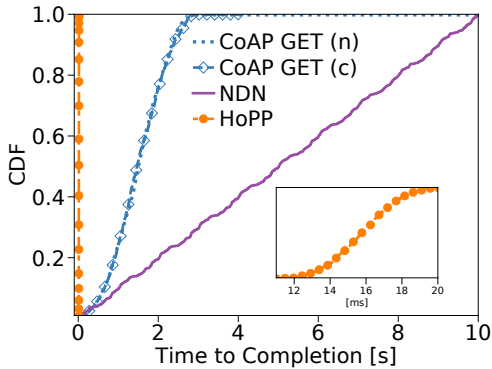
Pull protocols

Single-hop: Push vs. Pull

Time to content arrival for unscheduled publishing every [1 ... 3] s, content request every 1 s



Push protocols



Pull protocols

Problem of Stateful Forwarding in NDN

- Interests arrive at higher rate than content
  - $\Rightarrow$ Open PIT states accumulate
- PIT size very limited in constrained IoT scenario
- Two possible strategies:
  - Discard newly arriving Interests
  - Overwrite PIT states
  - $\Rightarrow$ Leads to delays or loss

Multi-hop: Characteristics

- Radio interference
- Additional link- & network-layer retransmissions
- Higher link stress

Single-hop vs. Multi-hop: Content Arrival

	Single-hop (50 ms)	Multi-hop (5 s)

Single-hop vs. Multi-hop: Content Arrival

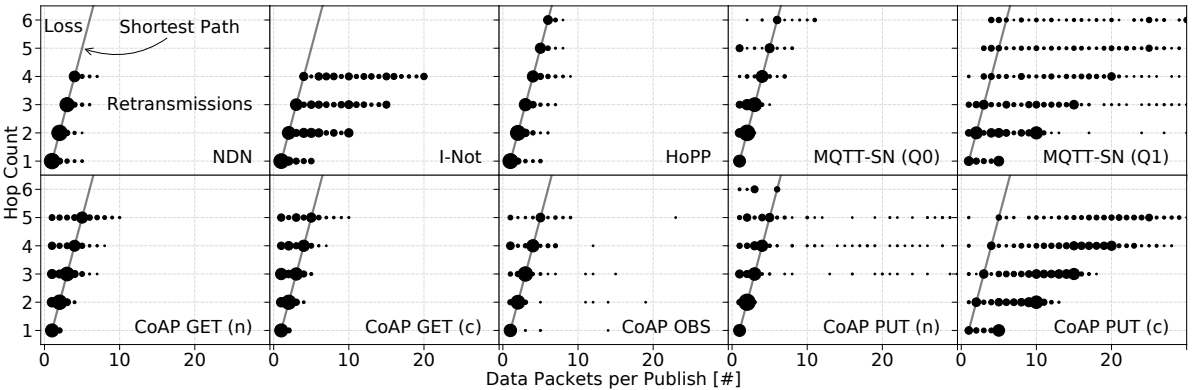
	Single-hop (50 ms)		Multi-hop (5 s)
	Avg. Delay [ms]	Success [%]	
Unreliable IP	8.0	97	
Reliable IP	305.0	99	
I-Not	7.2	100	
NDN & HoPP	13.6	100	
	Max. Delay [ms]	Protocol	
Unreliable IP	30.6	CoAP PUT (n)	
Reliable IP	5000.0	CoAP PUT (c)	
NDN & HoPP	27.9	HoPP	

Single-hop vs. Multi-hop: Content Arrival

	Single-hop (50 ms)		Multi-hop (5 s)	
	Avg. Delay [ms]	Success [%]	Avg. Delay [s]	Success [%]
Unreliable IP	8.0	97	0.03	57
Reliable IP	305.0	99	3.83	78
I-Not	7.2	100	1.98	68
NDN & HoPP	13.6	100	0.60	98
	Max. Delay [ms]	Protocol	Max. Delay [s]	Protocol
Unreliable IP	30.6	CoAP PUT (n)	0.2	CoAP GET (n)
Reliable IP	5000.0	CoAP PUT (c)	16.3	CoAP PUT (c)
NDN & HoPP	27.9	HoPP	13.7	HoPP

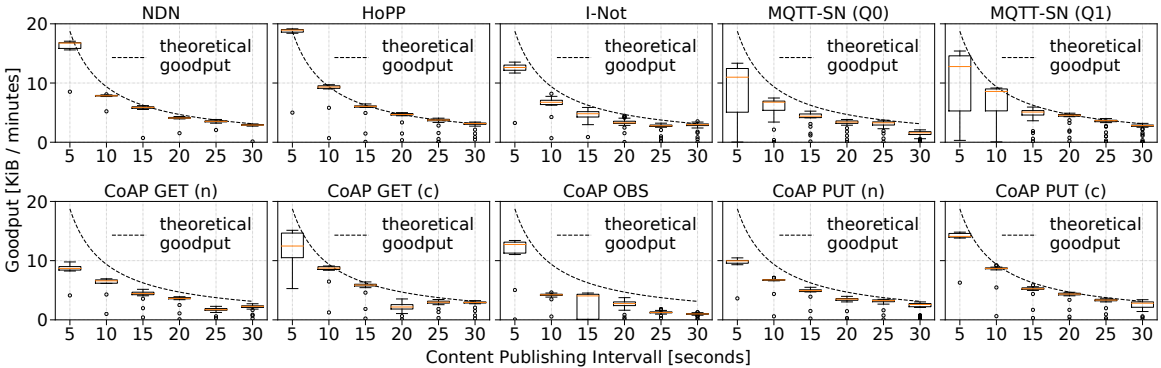
Multi-hop: Link Stress

Link traversal vs. shortest path using a 15 s publishing interval



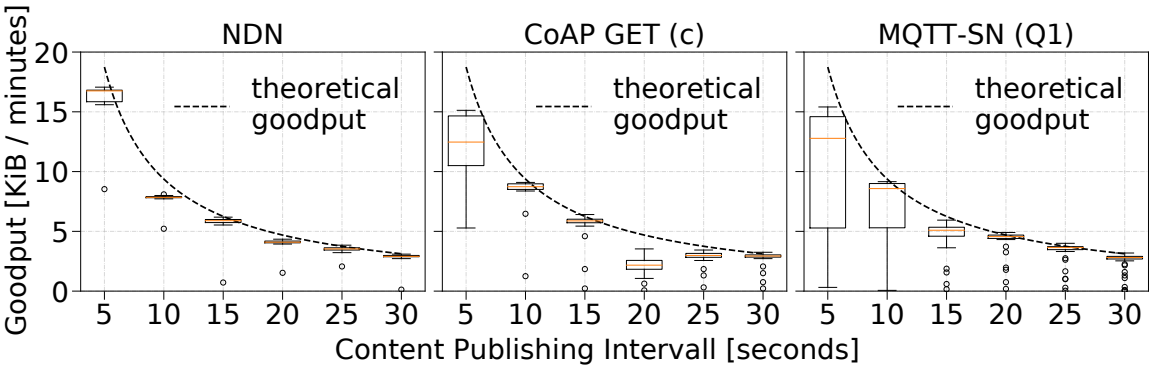
Multi-hop: Goodput

Goodput summaries



Multi-hop: Goodput

Goodput summaries for reliable protocols



Conclusion & Outlook

Takeaways

- All protocols are challenged by the constrained wireless IoT
  - Reliable transfer often fails
  - End-to-end acknowledgments stress lossy links
- NDN and HoPP are most robust and stable
  - Hop-wise caching enhances transport efficiency
  - NDN susceptible to PIT state overflow

Future Work

- Analyze flow control aspects with controlled cross-traffic
- Deploy protocols with full security features enabled