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

- Sensors and actuators connect to clouds
  - Today mainly based on MQTT
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- MQTT
  - Publish-subscribe protocol on TCP
  - Constrained IoT: MQTT-SN on UDP
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  - Request–response protocol on UDP
  - IETF solution for constrained IoT
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  - Constrained IoT: MQTT-SN on UDP
- CoAP
  - Request–response protocol on UDP
  - IETF solution for constrained IoT
- 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

GET
GET /temp

2.05 Content 21°C
CoAP

GET
GET /temp

2.05 Content 21°C

GET (c)
GET /temp

2.05 Content 22°C
CoAP

**GET**

GET /temp

2.05 Content 21°C

**GET (c)**

GET /temp

X

2.05 Content 21°C
CoAP

GET
GET /temp

2.05 Content 21°C

GET (c)
GET /temp

X

2.05 Content 21°C

GET /temp

2.05 Content 21°C
CoAP

GET
GET /temp

2.05 Content 21°C

PUT
PUT /temp 21°C

2.04 Changed

GET (c)
GET /temp

2.05 Content 21°C

GET /temp

2.05 Content 21°C

GET /temp

2.05 Content 21°C
CoAP

GET
GET /temp

2.05 Content 21°C

PUT
PUT /temp 21°C

2.04 Changed

GET (c)
GET /temp

X
2.05 Content 21°C

PUT (c)
PUT /temp 21°C

X
CoAP

**GET**
GET /temp

2.05 Content 21°C

**PUT**
PUT /temp 21°C

2.04 Changed

**GET (c)**
GET /temp

2.05 Content 21°C

**PUT (c)**
PUT /temp 21°C

2.04 Changed
CoAP

**GET**

GET /temp

2.05 Content 21°C

**PUT**

PUT /temp 21°C

2.04 Changed

**GET (c)**

GET /temp

2.05 Content 21°C

**PUT (c)**

PUT /temp 21°C

2.04 Changed

GET /temp

2.05 Content 21°C

GET /temp

2.05 Content 21°C

PUT /temp 21°C

2.04 Changed

PUT /temp 21°C

2.04 Changed
CoAP

**GET**

GET /temp

2.05 Content 21°C

**PUT**

PUT /temp 21°C

2.04 Changed

**OBS**

GET /temp [OBS]

2.05 Content 21°C

**GET (c)**

GET /temp

X

2.05 Content 21°C

**PUT (c)**

PUT /temp 21°C

X

2.04 Changed

**GET (c)**

GET /temp

2.05 Content 21°C

**PUT (c)**

PUT /temp 21°C

2.04 Changed

2.05 Content 22°C
MQTT-SN

CONNECT

CONNACK

REGISTER /temp

REGACK topic_{id}

SUBSCRIBE /temp

SUBACK
MQTT-SN

CONNECT

CONNACK

REGISTER /temp

REGACK topic_id

SUBSCRIBE /temp

SUBACK

Q0

PUBLISH topic_id 21°C
MQTT-SN

CONNECT

CONNACK

REGISTER /temp

REGACK $topic_id$

SUBSCRIBE /temp

SUBACK

Q0

PUBLISH $topic_id$ 21°C

Q1

PUBLISH $topic_id$ 21°C

X
MQTT-SN

CONNECT

CONNACK

REGISTER /temp

REGACK topic_id

SUBSCRIBE /temp

SUBACK

Q0

PUBLISH topic_id 21°C

PUBACK

Q1

PUBLISH topic_id 21°C

PUBACK
MQTT-SN

CONNECT

CONNACK

REGISTER /temp

REGACK topic_id

SUBSCRIBE /temp

SUBACK

Q0

PUBLISH topic_id 21°C

Q1

PUBLISH topic_id 21°C

PUBACK
ICN

NDN

Interest /temp

Data /temp 21°C
ICN

NDN

Interest /temp

Data /temp 21°C

ACK

Interest /temp

Data /temp 21°C

[ACK]

NAM

Interest /temp

Data /temp 21°C

ACK

Interest /temp

Data /temp 21°C
ICN

NDN
Interest /temp

Data /temp 21°C

I-Not
Interest /temp/ 21°C

Data /temp/ 21°C [ACK]

Interest /temp

Data /temp 21°C

Interest /temp

Data /temp 21°C

ACK

ACK

ACK
ICN

**ICN**

**NDN**

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
ICN

NDN
Interest /temp
Data /temp 21°C

I-Not
Interest /temp/21°C
Data /temp/21°C [ACK]

Interest /temp
Data /temp 21°C

Interest /temp
Data /temp 21°C

Interest /temp
Data /temp 21°C

ACK

ACK

ACK
ICN

NDN
Interest /temp
Data /temp 21°C
Interest /temp
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
Interest /temp
Data /temp 21°C
Interest /temp
Data /temp 21°C
# Properties at a Glance

<table>
<thead>
<tr>
<th></th>
<th>Current IoT Protocols</th>
<th>ICN Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GET</td>
<td>CoAP</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td>UDP</td>
<td>UDP</td>
</tr>
<tr>
<td><strong>Push</strong></td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Pull</strong></td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td><strong>Pub/Sub</strong></td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td><strong>Flow Control</strong></td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>(c)</td>
<td>(c)</td>
</tr>
</tbody>
</table>
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

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- Time to content arrival
- Link stress
- Goodput
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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
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

- CoAP OBS
- CoAP PUT (n)
- CoAP PUT (c)
- MQTT-SN (Q0)
- MQTT-SN (Q1)

### Pull protocols

- CoAP GET (n)
- CoAP GET (c)
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
  - Open PIT states accumulate

- PIT size very limited in constrained IoT scenario

- Two possible strategies:
  - Discard newly arriving Interests
  - Overwrite PIT states
    - 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

<table>
<thead>
<tr>
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<th>Single-hop (50 ms)</th>
<th>Multi-hop (5 s)</th>
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<tbody>
<tr>
<td><strong>Unreliable IP</strong></td>
<td>8.0</td>
<td>0.03</td>
</tr>
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<td>305.0</td>
<td>3.83</td>
</tr>
<tr>
<td><strong>I-Not</strong></td>
<td>7.2</td>
<td>1.98</td>
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<tr>
<td><strong>NDN &amp; HoPP</strong></td>
<td>13.6</td>
<td>0.60</td>
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### Max. Delay

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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

![Goodput Graphs for NDN, CoAP GET (c), and MQTT-SN (Q1)]
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