Delay-Tolerant ICN and Its Application to LoRa

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ICN Node

Internet

Fast wired network
(~ 20ms latency)
Different understanding of RTT

Fast wired network (~ 20ms latency)
Fast wired network  
(~ 20ms latency)  

Slow wireless network  
(> 20s latency)
What is LoRa?

High level facts
- Long range wireless (kilometers)
- Small energy consumption (millijoules)
- Limited throughput (bits per second)

Low level facts
- Chirp spread spectrum modulation
- Robust against interference, multi-path fading, doppler, ...
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Attractive technology for the constrained IoT
LoRa, LoRa**WAN**, and ICN

In *Proc. of ACM ICN, ACM, 2020.*

**Long-Range IoT:**
**Is LoRaWAN an option for ICN?**

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7th ACM Conference on Information-Centric Networking (ICN 2020)
LoRa, LoRaWAN, and ICN

Unreliable wireless uplink communication

Centralization prevents edge scenarios and complicates data sharing
Long-Range ICN for the IoT: Exploring a LoRa System Design

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Abstract—This paper presents LoRa-ICN, a comprehensive IoT networking system based on a common long-range communication layer (LoRa) combined with Information-Centric Networking (ICN) principles. We have replaced the LoRaWAN MAC protocol and employed a new radio interface that allows for different mappings of ICN message semantics, which improves robustness properties of current LoRaWAN systems. Furthermore, built-in caches in ICN facilitate more efficient LoRa communication overhead, whereas link capacity is scarce and expensive. Named and authenticated data access enables location-independence since applications can access named data directly, without resorting to lower-layer addresses. Furthermore, built-in caches in ICN facilitate more efficient LoRa communication overhead, whereas link capacity is scarce and expensive. Named and authenticated data access enables location-independence since applications can access named data directly, without resorting to lower-layer addresses. Thus, our design provides a basis for efficient ICN and energy-efficient long-range communication. In summary, our main contributions are:

1) The design of ICN over LoRa, including a suitable DSME and multi-channel MAC layer, and FLoRa to simulate LoRa-type devices—and a proof-of-concept demonstration of our adaptation layers in that system. (§ V)

2) Based on our simulation results, we derive preferred mappings of ICN message semantics in LoRa scenarios. (§ VI)

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LoRa, LoRaWAN, and ICN

Long-range ICN system design (simulated)

ICN / 802.15.4 DSME / LoRa

ICN: offload wireless, decrease latency, facilitate sleep
DSME: deterministic, reliable, low-power
LoRa, LoRaWAN, and ICN

Long-range ICN system design (simulated)

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DSME: deterministic, reliable, low-power

RTTs 20–120 s challenge practical ICN forwarders
We aim for a delay-tolerant integration of LoRa with vastly different RTTs into a ‘regular’ ICN network.
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To achieve this, we:

1. Implement the 802.15.4 DSME MAC on top of LoRa PHY in the IoT OS RIOT
2. Introduce new gateway behavior and leverage recently proposed ICN extensions
3. Experimentally compare ‘Vanilla’ ICN and the extensions on IoT hardware
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Outline

Problem Statement

System Overview

Implementation and Deployment

Evaluation

Conclusion & Outlook
Problem Statement
Dual Function of Interests

Sending Interest
▶ **Trigger** data transmission
▶ **Trigger** re-transmission on loss
▶ Mechanism is **unspecified**

Consumer Re-transmission
▶ Knowledge about app. time domain
▶ PIT timeout vs retrans. timer
▶ Requires on-path PIT state to expire
▶ But RTT requires long state for data

Pending Interest
▶ Implement **symmetric forwarding**
▶ Record downstream face for **data fwd.**
▶ Enable Interest **aggregation** (suppression)

Interest Lifetime (**NDN**)  
▶ Default of 4 seconds is too **short**
▶ Forwarders might object **non-standard values**
▶ Routers might object spending **memory**
▶ Unpredictably changing RTT
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Alternative Retransmission Techniques

**In-network retransmission** (e.g., CCN-lite)
- Hop-wise retransmit by every forwarder
- No suffering from Interest aggregation
- Allows long-lived PIT state
- On-path nodes need to guess suitable timeouts

**Retransmission suppression** (e.g., NFD)
- Suppress same name Interest in suppression interval
- RTT estimation should permit reasonable consumer retrans. intervals
- Main purpose is prevention of DDoS attacks
- Long and vastly differing RTT still challenging
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In-network retransmission (e.g., CCN-lite)

**Guessing** suitable intervals is **challenging**
Cannot expect forwarders to **honor** InterestLifetime

**Deal** with high and differing RTTs **explicitly**
No **interfering** with network layer InterestLifetime

Relieve forwarders from **domain** specific knowledge

- Main purpose is prevention of DDoS attacks
- Long and vastly differing RTT still challenging
System Overview
Gateway Node Requirements

**Gateway operation**
- Gateway serves one LoRa network
- Application agnostic caching forwarder
- Connect narrowband LoRa to broadband ICN network
- Leverage knowledge about last-hop delays → Adjust PIT timeout and InterestLifetime

**Node registration**
- Nodes register prefixes at gateway
- Gateway acts as a node custodian

**Data provisioning by nodes**
- Asynchronous data provisioning by unsolicited data
- Gateway only caches data from registered nodes
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Two Delay-Tolerant ICN Protocols

1. Consumer-initiated

- Internet consumers request arbitrary content
- RICE [31] supports vastly longer and varying delays
- On 1st Interest:
  - Gateway checks if node falls under registered prefix
  - Gateway forwards Interest to LoRa node
  - Gateway returns estimated wait time
- On 2nd Interest:
  - Gateway satisfies request from content store (CS)
Two Delay-Tolerant ICN Protocols

2. Producer-initiated

- LoRa nodes place content in gateway cache, if registered
- Leverage phoning home use case of reflexive forwarding [46] (two nested Interest/Data exchanges)
- Gateway sends Interest to Internet node, indicating name
- Consumer returns reflexive Interest and retrieves content
- Optional data ACK terminates initial Interest
Protocol Overview

Delay-tolerant Data Retrieval

Fast network

Slow network

Reflexive Push

Fast network

Slow network

Interest | data | control func. | long delay | reg. lookup | do not cache | PIT timeout

Vanilla (1)

Baseline scenario, common parameter settings

InterestLifetime: 4 s

Retransmission interval: 1 s

Vanilla (2)

Delay-aware consumer

InterestLifetime: 60 s

Retransmission interval: 15 s

Vanilla (3)

Like Vanilla (2) but forwarders do adopt InterestLifetime
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- Baseline scenario, common parameter settings
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Implementation and Deployment
System Setup

LoRa Device

- Low-power, long-range sensor application
- ARM Cortex-M4 @ 64 MHz
  256 kB RAM/1 MB ROM
- Semtech SX 1276 LoRa radio
- Operated by RIOT and our network stack

Gateway

- Same hardware (reduce impl. overhead)
- Two network interfaces:
  1. Wireless coordinator for LoRa
  2. Wired Ethernet for Internet

Internet

- Emulated RIOT-native instances
- Virtual TAP bridge to gateway
- Forwarder and consumer emulated in Mininet
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![Diagram showing network setup with LoRa Device, Gateway, and Internet interfaces.]
Evaluation
Completion Time and Resilience

Vanilla (1)

- Consumer retransmission
- Consumer retransmission (5% loss)
- In-network retransmission
- In-network retransmission (5% loss)
Completion Time and Resilience

Vanilla (1)

Expired PIT state prevents long RTTs

Futile retransmissions introduce notable overheads

- Consumer retransmission
- In-network retransmission
- Consumer retransmission (5% loss)
- In-network retransmission (5% loss)
Completion Time and Resilience

**Vanilla (1)**

**Vanilla (2)**

<table>
<thead>
<tr>
<th>Completion Time [s]</th>
<th>CDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>0.02</td>
</tr>
<tr>
<td>20</td>
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<tr>
<td>30</td>
<td>0.06</td>
</tr>
<tr>
<td>40</td>
<td>0.08</td>
</tr>
<tr>
<td>50</td>
<td>1.00</td>
</tr>
</tbody>
</table>

- **Consumer retransmission**
- **In-network retransmission**

- **Consumer retransmission (5% loss)**
- **In-network retransmission (5% loss)**
Application-aware consumers recover losses
Performance depends on ‘arbitrary’ poll interval
Susceptible to varying delays
Completion Time and Resilience

Vanilla (1)  
Vanilla (2)  
Vanilla (3)  

- **Consumer retransmission**  
- **In-network retransmission**  
- **Consumer retransmission (5% loss)**  
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Completion Time and Resilience

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Completion Time and Resilience

Vanilla (1)  Vanilla (2)  Vanilla (3)

1.0 1.2 1.4 1.6 1.8 2.0
0.950
0.975
1.000
1.025
1.050

Consumer retransmission
Consumer retransmission (5% loss)
In-network retransmission
In-network retransmission (5% loss)

**Cannot** expect forwarders to **adopt** arbitrary PIT timers

Long PIT state **unreliable** with consumer retransmissions

In-network retransmissions **require RTT knowledge**
Completion Time and Resilience

- **Vanilla (1)**
- **Vanilla (2)**
- **Vanilla (3)**
- **Delay-tolerant data retrieval**

Each graph represents the cumulative distribution function (CDF) of completion time in seconds. The x-axis represents the completion time, while the y-axis represents the CDF. Different lines in each graph indicate different retransmission strategies:

- **Orange line**: Consumer retransmission
- **Dashed orange line**: Consumer retransmission (5% loss)
- **Blue line**: In-network retransmission
- **Dashed blue line**: In-network retransmission (5% loss)
Completion Time and Resilience

Vanilla (1)   Vanilla (2)   Vanilla (3)   Delay-tolerant data retrieval

0.16
0.8
1.0

CDF

Overcomes requirements of long PIT state and polling
Relieves consumers and forwarders of estimating RTT

Completion Time [s]   Completion Time [s]   Completion Time [s]   Completion Time [s]

- Orange: Consumer retransmission
- Orange dashed: Consumer retransmission (5% loss)
- Blue: In-network retransmission
- Blue dashed: In-network retransmission (5% loss)
Completion Time and Resilience

Reversed transaction flow reflects IoT data generation

Facilitates reliable and timely transactions

Most efficient for low-power sensor node
Evaluation of communication- and system overhead in our paper!
Conclusion & Outlook
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**In this work, we ...**
... observed that interconnecting networks with vastly different RTTs is challenging
... found that ICN has potential to enable robust communication to edge networks
... contributed an implementation of ICN/DSME/LoRa and two ICN-style extensions

Our results show that ...
... our Internet-consumer and LoRa-producer initiated pattern exhibit high reliability
... compared to Vanilla ICN, they enable targeted completion time and overcome polling
... ICN/DSME/LoRa provides low-power consumption with lifetimes >1 y (AA battery)

**In future work we will ...**
... implement a gateway estimator model including domain knowledge ...
... explore security including gateway trust, LoRa node authentication ...
... evaluate complex topologies including multi-gateway, node-to-node ...
... investigate additional use cases including RMI, firmware updates ...
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We support reproducible research.