Delay-Tolerant ICN and Its Application to LoRa

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9th ACM Conference on Information-Centric Networking (ICN 2022)  
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Fast wired network
(~ 20ms latency)
ICN Node

Internet

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

Fast wired network (~ 20ms latency)
ICN Node

Fast wired network
(~ 20ms latency)

Slow wireless network
(> 20s latency)

LoRa Device

Internet

Gateway
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, LoRaWAN, 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 layer with an IEEE 802.15.4 Deterministic and Synchronous Multi-Channel Extension (DSME). This multifaceted MAC layer with an IEEE 802.15.4e [1], a flexible MAC layer that consists of contention-access and contention-free periods, and, second, its integration into LoRa is missing, yet. We argue that ICN empowers LoRa Gateways to act as routers, without the need to base our system design on the following four requirements: (i) enabling LoRa networks and Nodes in these networks to communicate directly with hosts on the Internet; (ii) empowering LoRa Gateways to act as routers, without the need to
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)
ICN / 802.15.4 DSME / LoRa
ICN: offload wireless, decrease latency, facilitate sleep
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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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
Gateway Node Requirements

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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)

![Delay-tolerant Data Retrieval Diagram]

- Fast network
- Slow network
- **Interest**
- **data**
- **control func.**
- **long delay**
- **reg. lookup**
- **do not cache**
- **PIT timeout**

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Two Delay-Tolerant ICN Protocols

2. Producer-initiated

 iniciated

▶ 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
- /p
- /p Δt
- /p <dat>

- InterestLifetime: 4 s
- Retransmission interval: 1 s

Vanilla (2)

- Delay-aware consumer
- InterestLifetime: 60 s
- Retransmission interval: 15 s

Vanilla (3)

- Like Vanilla (2)
- Forwarders do adopt InterestLifetime

Reflexive Push

- Fast network
- Slow network
- /p
- /p <dat>
- /p ACK

- data

- Interest
- data
- control func.
- long delay
- reg. lookup
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- PIT timeout
Protocol Overview

Vanilla (1)
- Baseline scenario, common parameter settings
- InterestLifetime: 4 s
- Retransmission interval: 1 s

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- InterestLifetime: 60 s
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Reflexive Push

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Slow network
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Legend:
- Interest
- Data
- Control func.
- Long delay
- Reg. lookup
- Do not cache
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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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Evaluation
Completion Time and Resilience

**Vanilla (1)**

![Graph showing CDF of completion time](image)

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

Vanilla (1)

Expire 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)

- 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)
---|---|---

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Completion Time and Resilience

**Vanilla (1)**

**Vanilla (2)**

**Vanilla (3)**

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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

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

CDF

Completion Time [s]

0.0 0.2 0.4 0.6 0.8 1.0

0.00 0.02 0.04 0.06 0.08 0.10 0.12

0 10 20 30 40 50

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

Overcomes requirements of long PIT state and polling

Relieves consumers and forwarders of estimating RTT
Completion Time and Resilience

Vanilla (1)  |  Vanilla (2)  |  Vanilla (3)  |  Delay-tolerant data retrieval  |  Reflexive push

CDF

0.0 0.2 0.4 0.6 0.8 1.0
0.00 0.02 0.04 0.06 0.08 0.10
0 10 20 30 40 50
0 10 20 30 40 50
0 10 20 30 40 50
0 10 20 30 40 50

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

- Orange: Consumer retransmission
- Blue: In-network retransmission
- Dashed orange: Consumer retransmission (5% loss)
- Dashed blue: In-network retransmission (5% loss)
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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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 >1y (AA battery).

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Thank You!

We support reproducible research.

https://github.com/inetrg/ACM-ICN-LoRa-ICN-2022.git