Delay-Tolerant ICN and Its Application to LoRa

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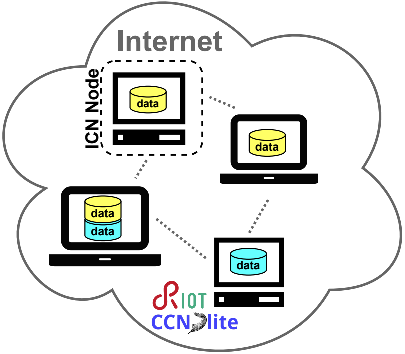
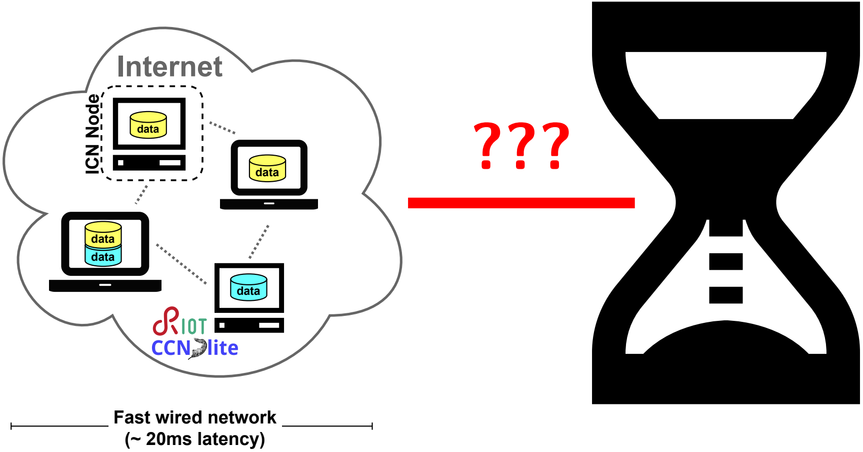


Fast wired network
(~ 20ms latency)


Internet
ICN Node
data
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???
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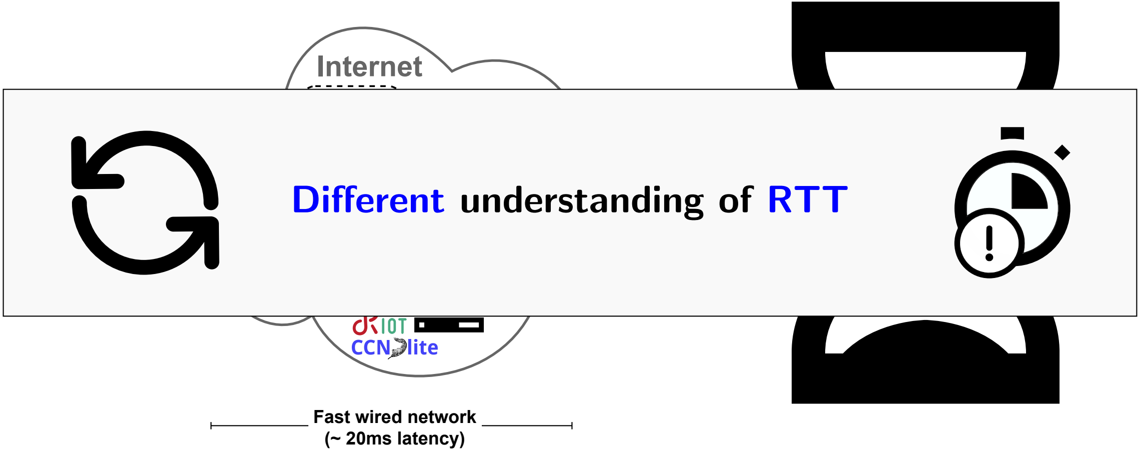
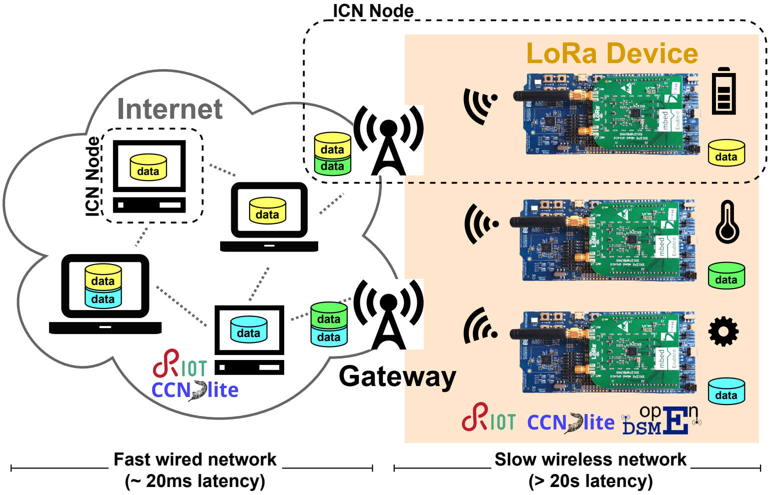

Internet
Different understanding of RTT
IOT
CCN lite
Fast wired network
(~ 20ms latency)



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LoRa Device
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Gateway
RIOT
CCNlite
RIOT
CCNlite
openDSME
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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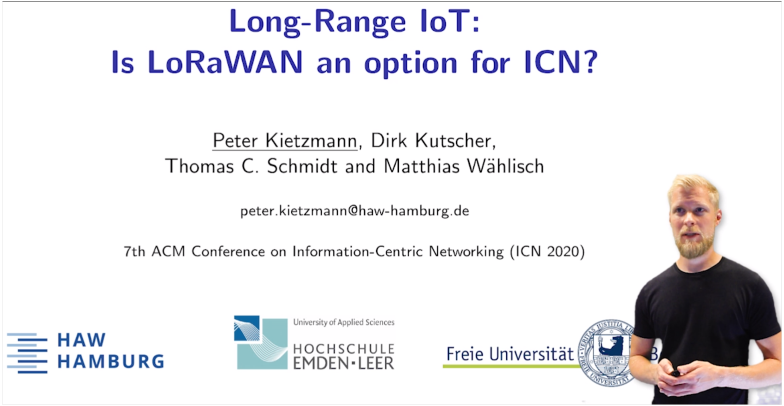
Attractive technology for the constrained IoT

LoRa, LoRa**WAN**, and ICN

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



LoRa, LoRa**WAN**, and ICN

Unreliable wireless uplink communication

Centralization prevents edge scenarios and complicates data sharing

LoRa, LoRa**WAN**, and ICN

In *Proc. of IFIP Networking, IEEE, 2022.*

Long-Range ICN for the IoT: Exploring a LoRa System Design

Peter Kietzmann*, José Alamos*‡, Dirk Kutscher†, Thomas C. Schmidt*, Matthias Wählisch‡
HAW Hamburg, Germany* Hochschule Emden/Leer, Germany† Freie Universität Berlin, Germany‡
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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**

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

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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

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LoRa, LoRa**WAN**, and ICN

Long-ra **ulated)**

I **a**

ICN: offloa **facilitate sleep**

DSN **w-power**

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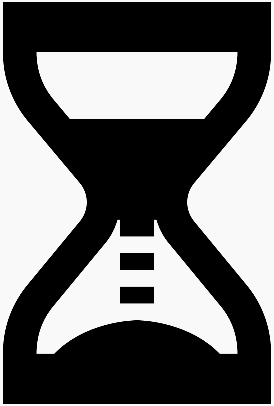

RTTs 20–120 s challenge practical ICN forwarders

We aim for a delay-tolerant integration of LoRa with vastly different RTTs into a 'regular' ICN network

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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

Pending Interest

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

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

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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Alternaitve 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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Alternaitve Retransmission Techniques

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

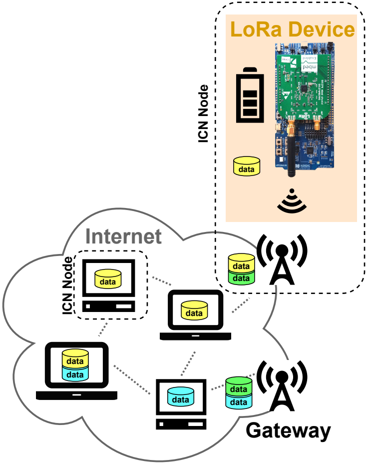
Gateway Node Requirements

Gateway operation

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

Node registration

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



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- Asynchronous data provisioning by unsolicited data
- Gateway only caches data from registered nodes

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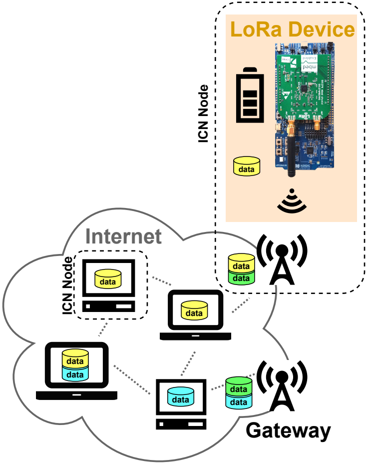

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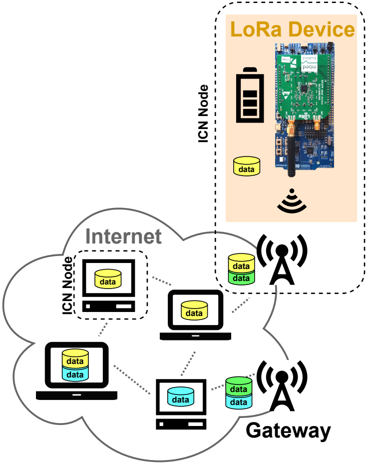

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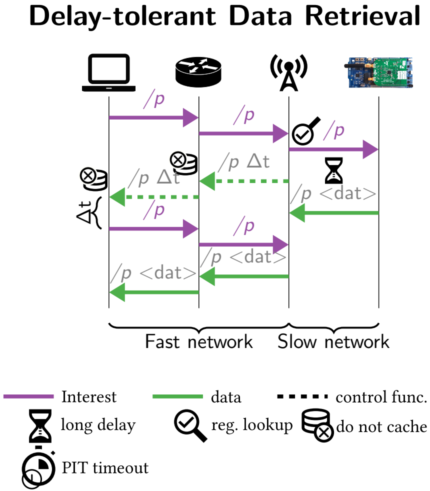
Two Delay-Tolerant ICN Protocols

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)

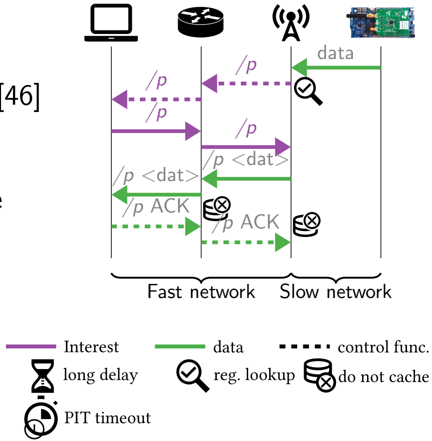


Two Delay-Tolerant ICN Protocols

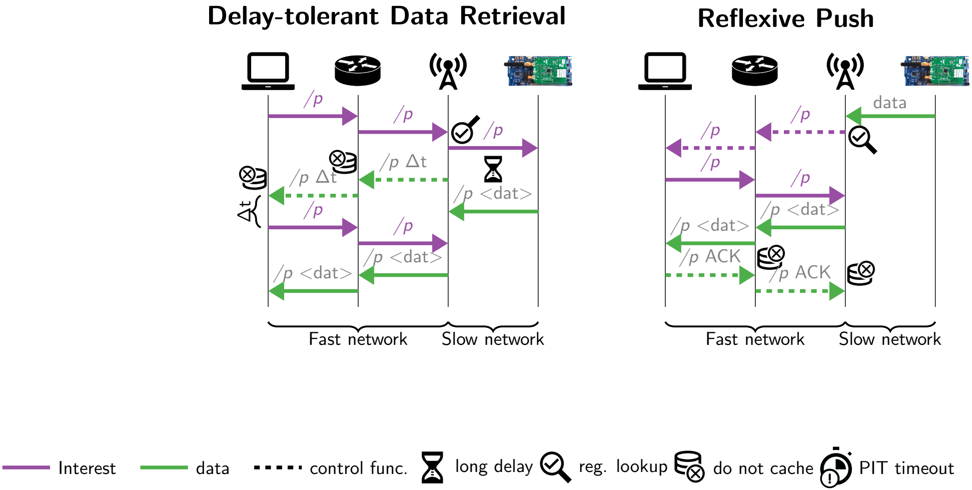
2. Producer-initiated

- 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

Reflexive Push



Protocol Overview



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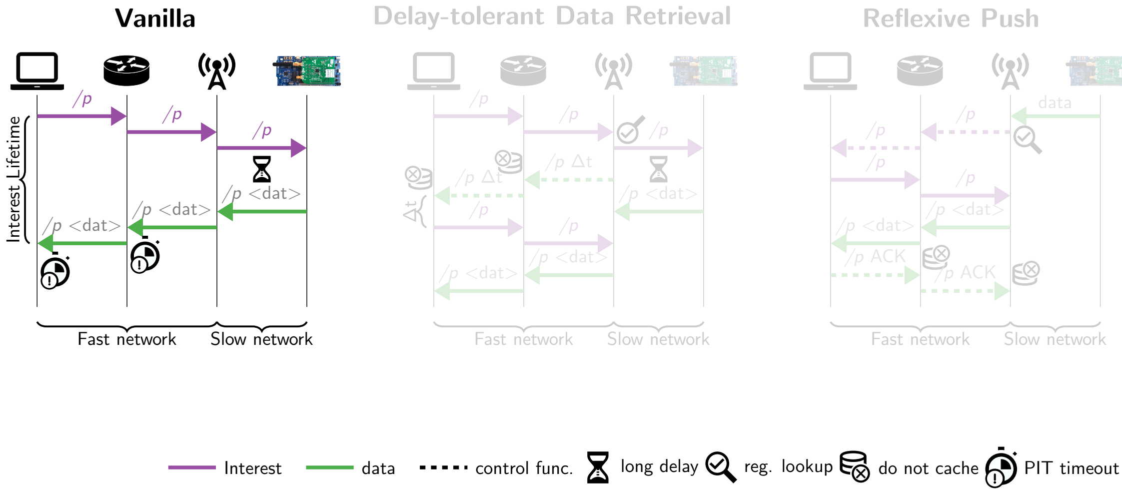

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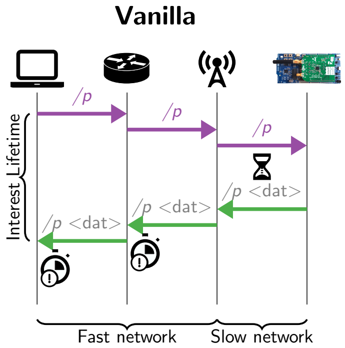
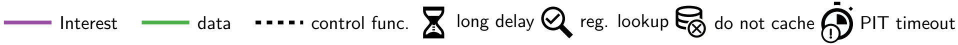


Vanilla (1)

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



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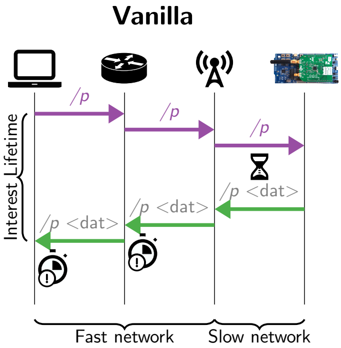

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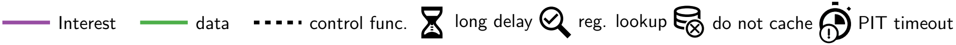
Vanilla (2)

- Delay-aware consumer
- InterestLifetime: 60 s
- Forwarders do **not** adopt InterestLifetime
- Retransmission interval: 15 s



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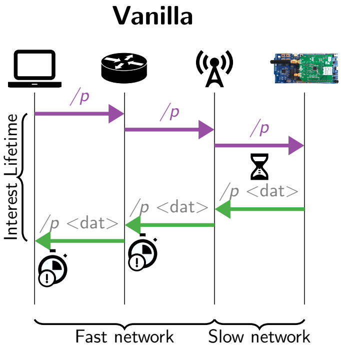

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Vanilla (3)

- Like **Vanilla (2)** but forwarders **do** adopt InterstLifetime

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

Implementation and Deployment

System Setup

LoRa Device

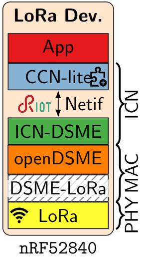
- Low-power, long-range sensor application
- ARM Cortex-M4 @ 64 MHz
  256 kB RAM/1 MB ROM
- Semtech SX 1276 LoRa radio
- Operated by RIOT and our network stack

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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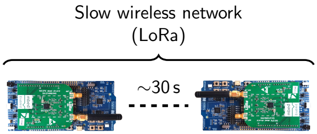

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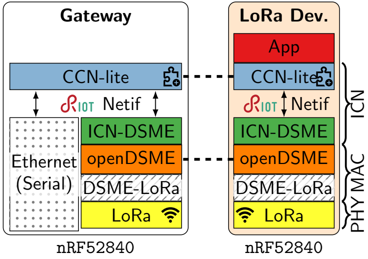

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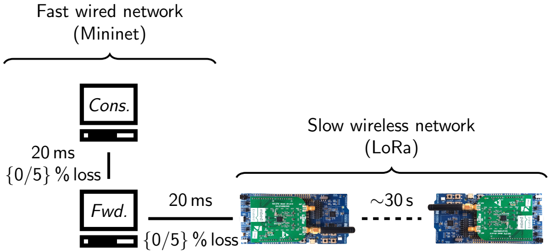
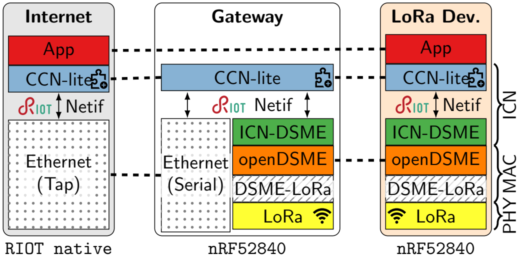
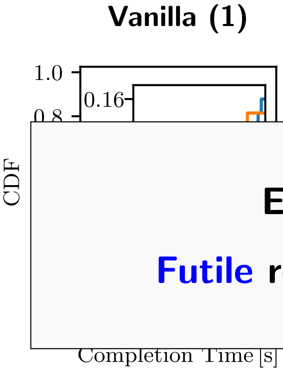




Evaluation

Completion Time and Resilience

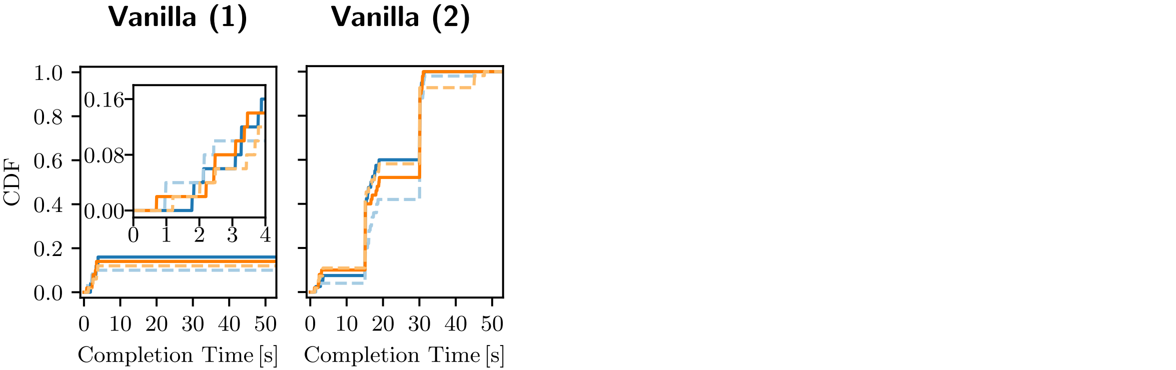
Completion Time and Resilience



Expired PIT state prevents long RTTs

Futile retransmissions introduce notable overheads

Completion Time and Resilience



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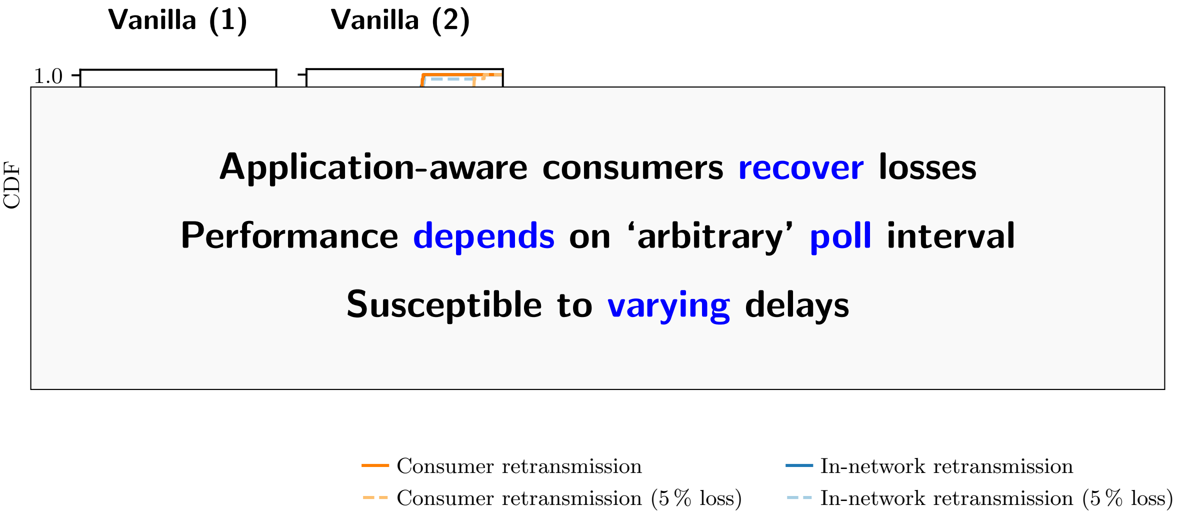
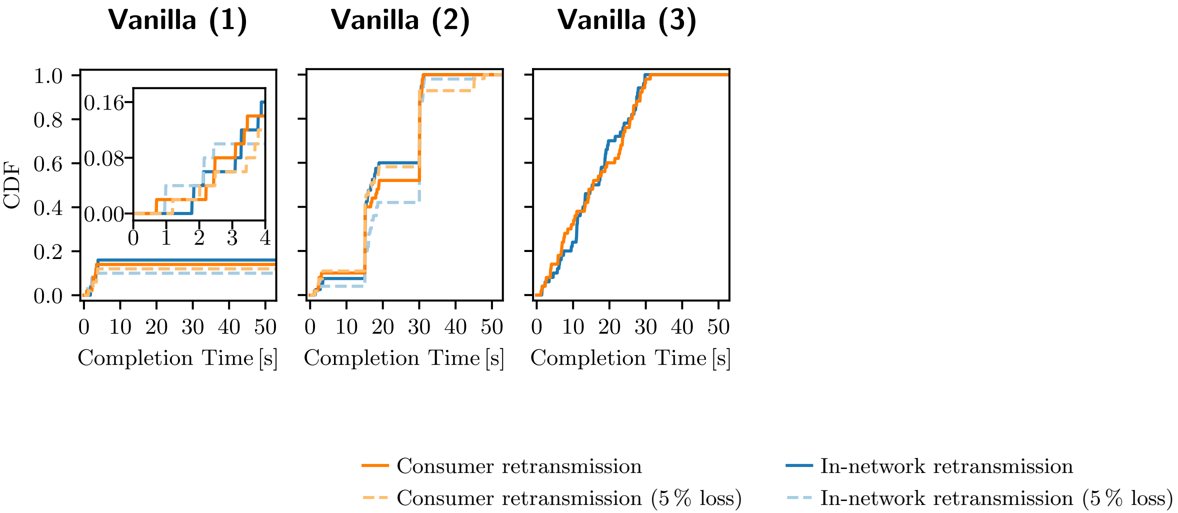


Application-aware consumers recover losses

Performance depends on ‘arbitrary’ poll interval

Susceptible to varying delays

Completion Time and Resilience



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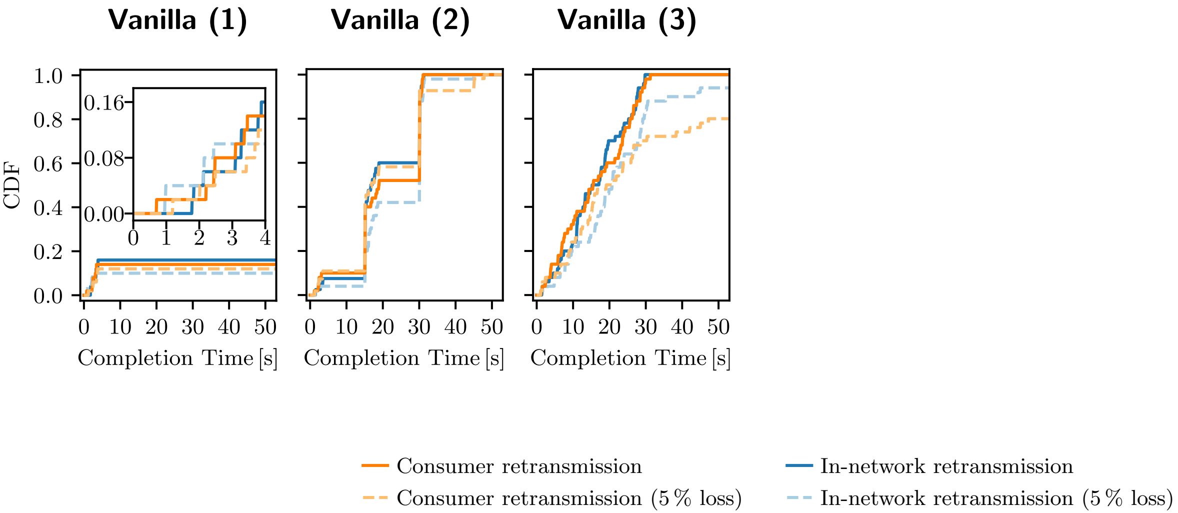

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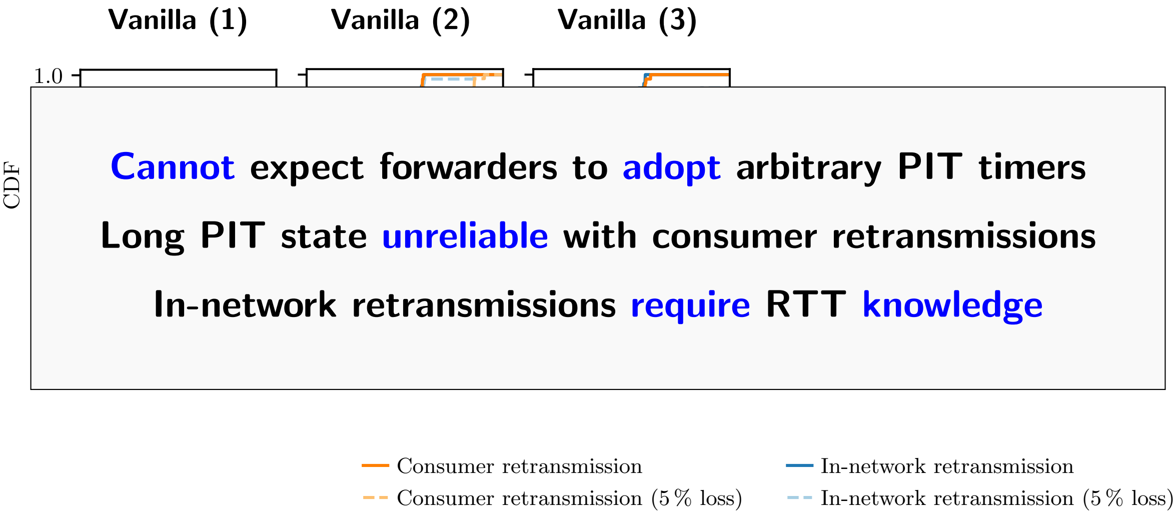

Cannot expect forwarders to adopt arbitrary PIT timers

Long PIT state unreliable with consumer retransmissions

In-network retransmissions require RTT knowledge

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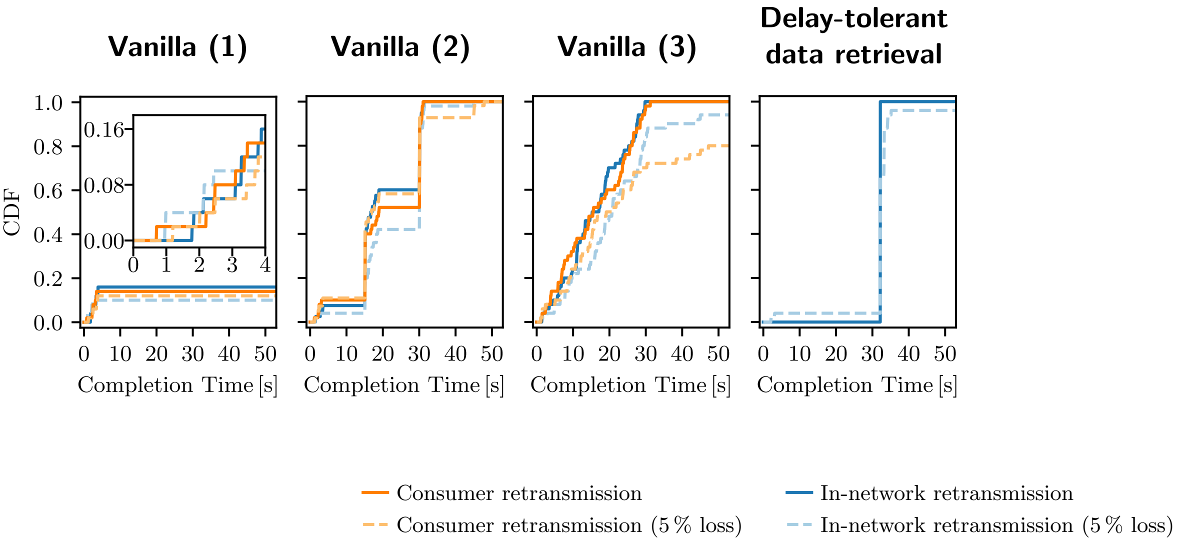

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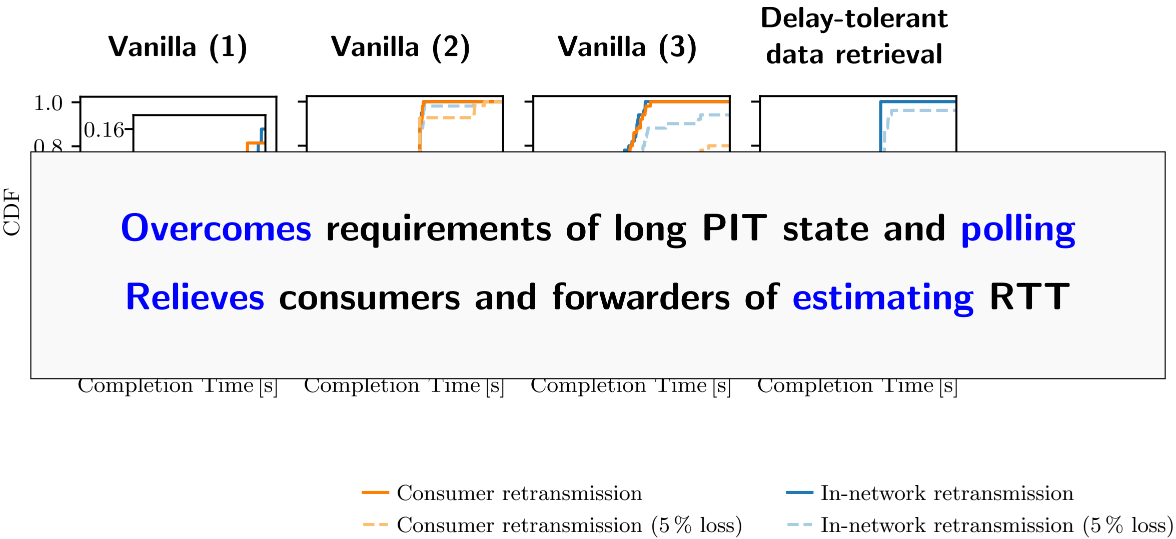
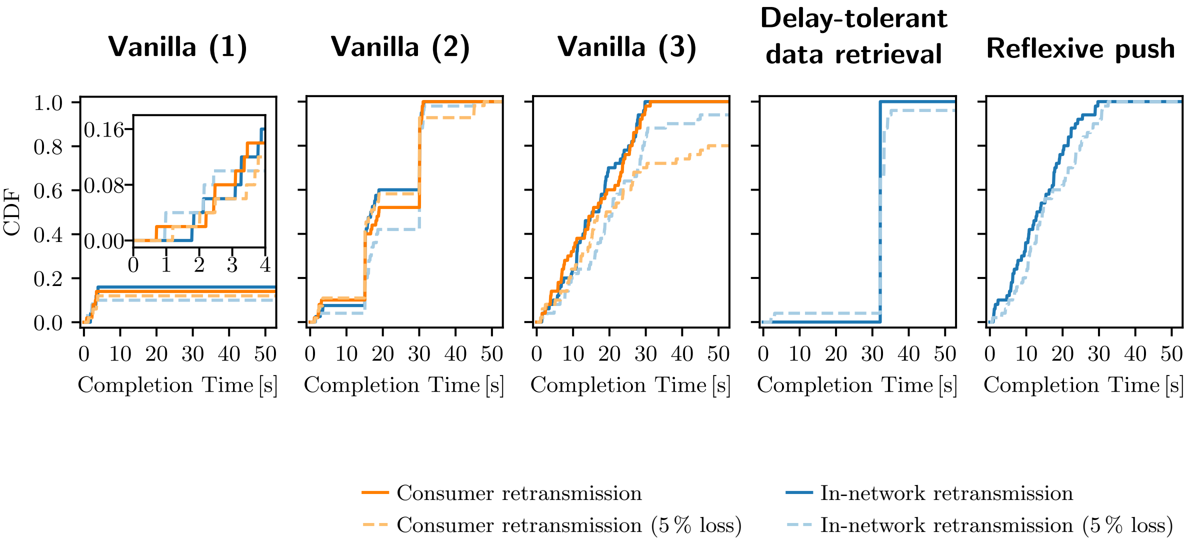


Overcomes requirements of long PIT state and polling

Relieves consumers and forwarders of estimating RTT

Completion Time and Resilience



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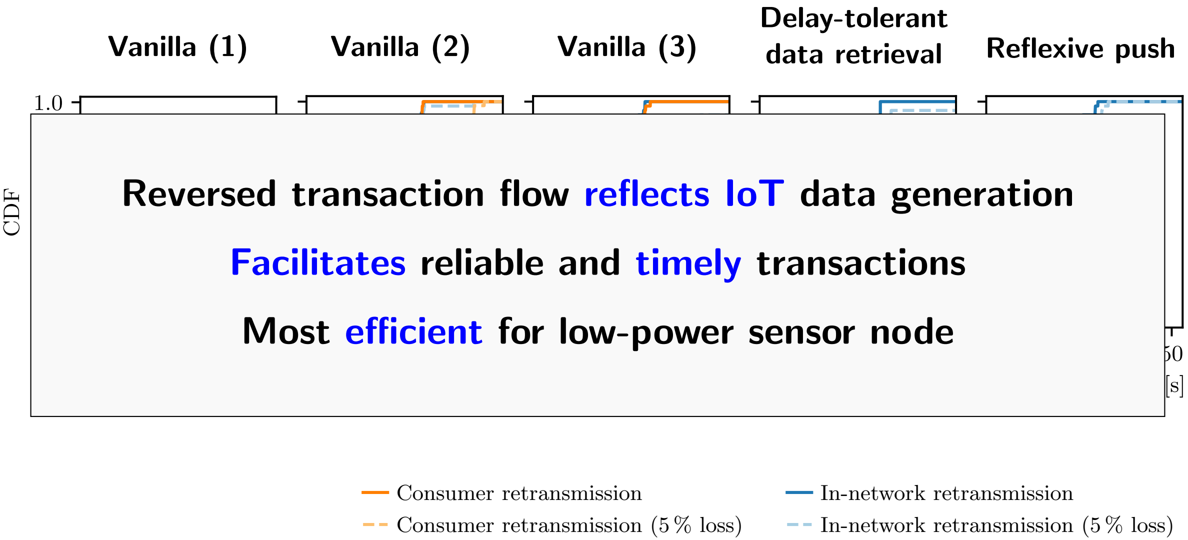

Reversed transaction flow reflects IoT data generation

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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Thank You!

We support reproducible research.

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