Bluetooth Mesh under the Microscope: How much ICN is Inside?

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HAW HAMBURG

Freie Universität Berlin

Starting Point

The Bluetooth mesh standard adopted last year is a wireless technology based on the ICN principles. [...] It implements all of the major paradigms of information-centric networking in order to enable simplicity, scalability and reliability [...]. — SILVAIR. *Information-centric networking – a revolutionary approach to wireless lighting control, 2018.*
`http://silvair.com/resources/information-centric-networking/`

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What is BT mesh? How does it compare to ICN?

Related Work

		BT mesh	ICN
[SILVAIR'18]	**BT mesh standard based on ICN principles** No technical detail	✓	✓
[ICN'18]	**NDNoT Framework for IoT** No technical evaluation	✘	✓
[SenSys'17]	**BLE and BT mesh performance analysis** No ICN at all	✓	✘
[SoftCOM'15]	**Service mediation in multi-hop BLE/NDN** No comparison in ICN	✘	✓
[Theses'14]	**Bluetooth convergence layer for NetInf** No low-power BT	✘	✓

Outline

Motivation why we started this work

BT mesh overview and comparison to ICN principles

Experimental evaluation in the FIT IoT-LAB testbed

Outlook how ICN can benefit from BT mesh concepts

BT mesh overview and comparison to ICN principles

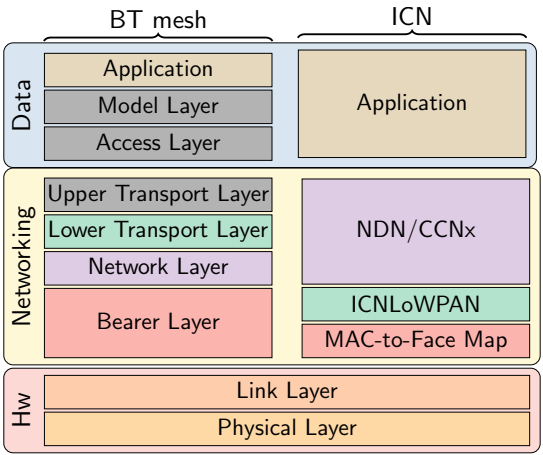
Bluetooth (BT) Evolution

- BT (since 1.0) $\rightarrow$ BLE (since 4.0) $\rightarrow$ **BT mesh** (independent) & BT 5.0++

Bluetooth (BT) Evolution

- BT (since 1.0) → BLE (since 4.0) → **BT mesh** (independent) & BT 5.0++
  - Uses BLE hardware
  - Enables multi-hop
  - Adds many-to-one
  - Adds many-to-many

Stack Organization



BT mesh

- Full vertical stack
- Data model per device type
- Publish-subscribe data exchange
- Segmentation on transport layer
- Tied to single interface BLE radio

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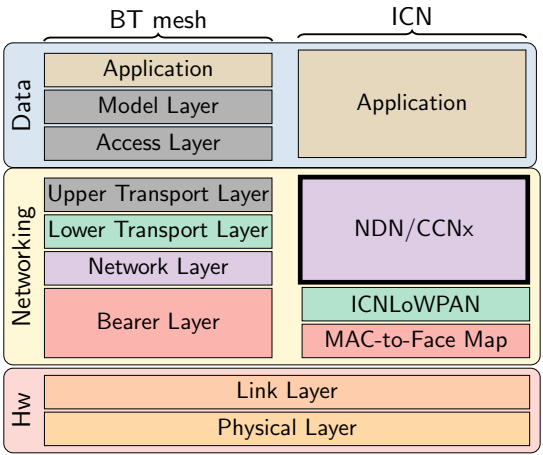


BT mesh

- Full vertical stack
- Data model per device type
- Publish-subscribe data exchange
- Segmentation on transport layer
- Tied to single interface BLE radio

ICN

- Relies on supporting protocols
- No requirement on format of names
- Convergence layer implements compression and segmentation
- Allows multi-interface of different types

MAC and Reliability

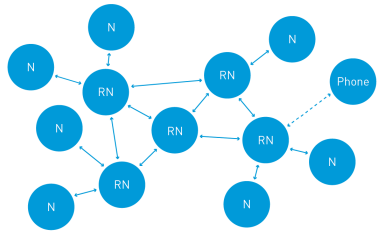
BT mesh

- TX on 3 broadcast channels
- Replicate packets up to 7x a priori
  → Multiple transmissions / packet
  → Tweaked according to roles
- RX scans on 3 channels consecutively

Routing and Forwarding

BT mesh

- Multi-hop & multi-path by forwarding all packets over broadcast
- *Managed flooding*:
  - Hop-limit counter
  - Message cache list known packets
  - Prevents redundant forwarding
  - Does **not** cache content
- Native support of group requests



Source: https://www.beaconzone.co.uk/BluetoothMeshBeacons

Names and Addresses

BT mesh

- Group addresses to label data streams
  - Unassigned
  - Unicast
  - Group: map to fixed roles (*all relays*, *all nodes*, ...)
  - Virtual: configurable groups
- Setup usually static during deployment
- Data is addressed not endpoint

→ **Content centric**

Publish-Subscribe

BT mesh

- Publish-subscribe w/o broker
- Enabled by broadcasting on link layer
- Advertise items to groups (**publish**)
- Filter items on receive (**subscribe**)
- Publish **can** be solicited for reliability

  $\rightarrow$ similar to ICN request/response

  (Standard advises against)

BT mesh vs ICN Comparison

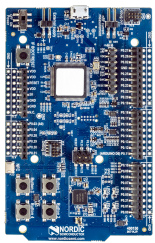
	BT mesh	**ICN**
MAC	Broadcast	Unspecified
Reliability	Replication	Retransmits on demand
Routing	No routing	FIB based routing
Forwarding	Managed flooding	FIB & PIT based forwarding
Names	Group addresses for data streams	Hierarchical tokenized names for data items
Addresses	Numeric representation	Semantic representation
Publish-Subscribe	Enabled without broker	Workarounds needed to avoid *push*

Experimental evaluation in the FIT IoT-LAB testbed

Testbed Deployment

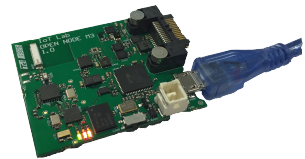
- ARM Cortex-M4F @ 64 MHz
- 64 kB RAM, 512 kB ROM
- BLE radio on SoC (1 Mbps)

- RIOT `2019.04` + NimBLE



- ARM Cortex-M3 @ 72 MHz
- 64 kB RAM, 512 kB ROM
- IEEE 802.15.4 radio (250 kbps)

- RIOT `2019.04` + CCN-lite

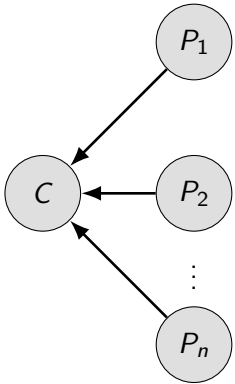


RIOT

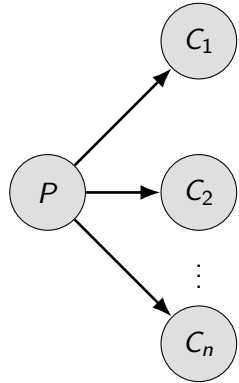
CCN-lite

Single-hop Topology w/ 10 Nodes

Many-to-one
9 publishers; 100 items/node; 5 s interval



One-to-many
1 publisher; 100 items; 1 s interval



→ Data flow
n: 9 nodes
C: Consumer
P: Producer

Multi-hop Line Topology w/ 10 Nodes

Many-to-one

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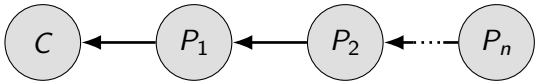

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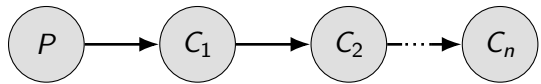
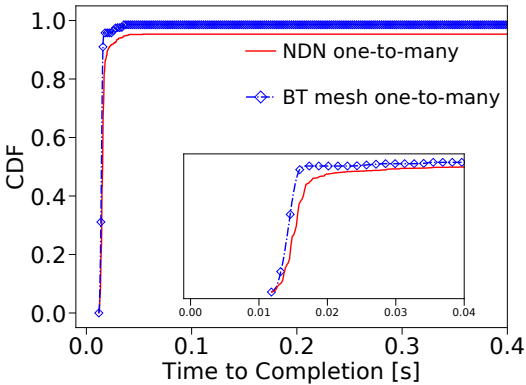


Time to Content Arrival

Single-hop



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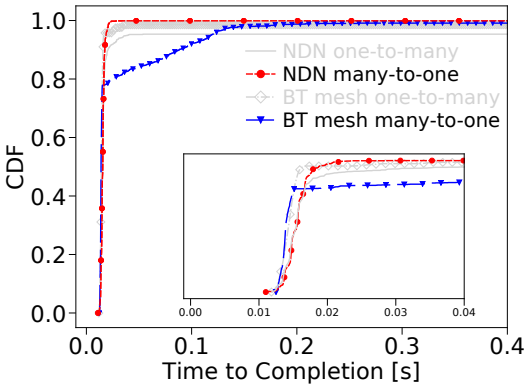

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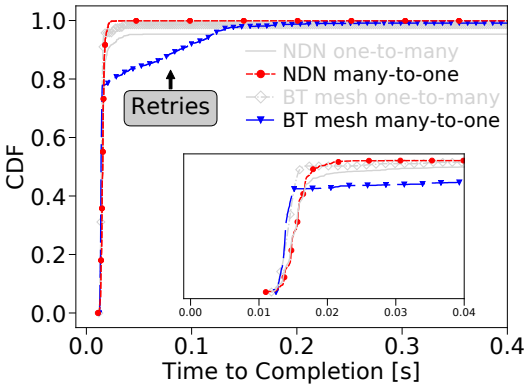

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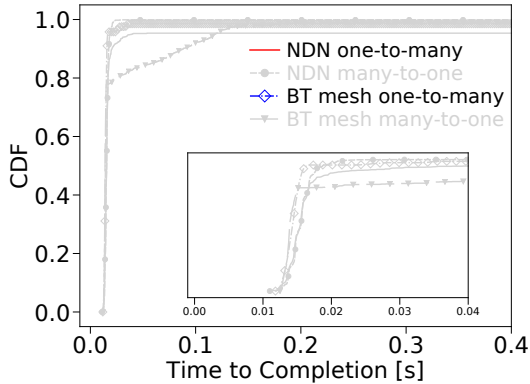
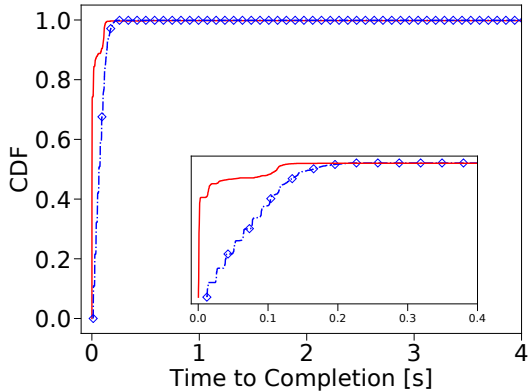


Multi-hop



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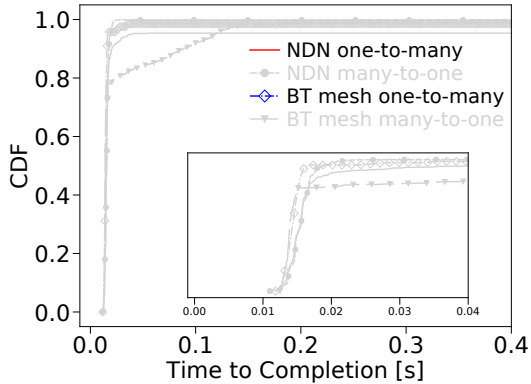

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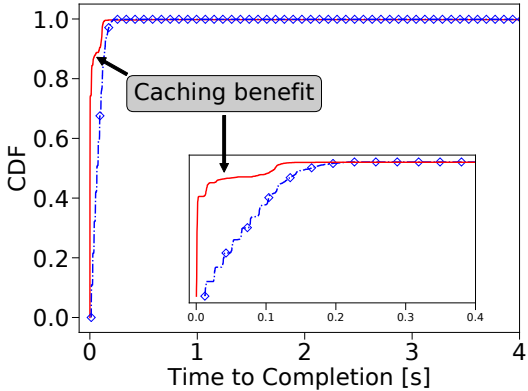

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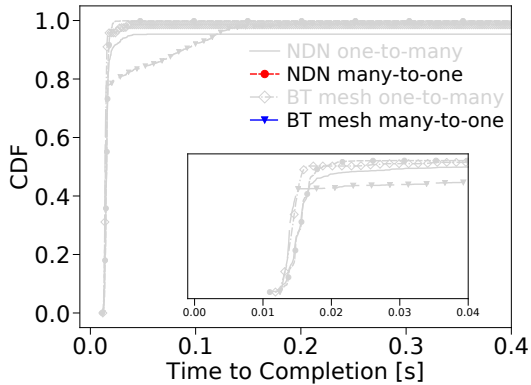

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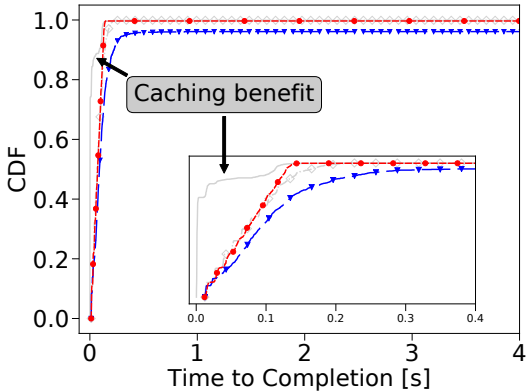
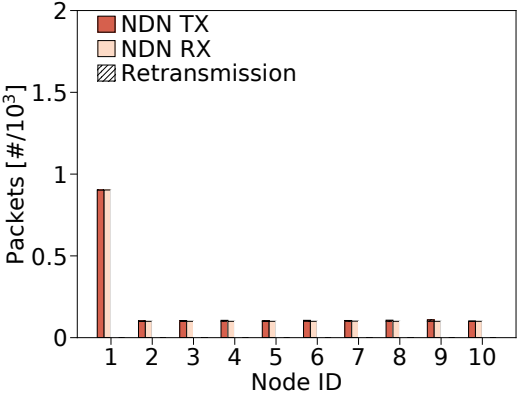


Traffic Load: One-to-Many

Single-hop



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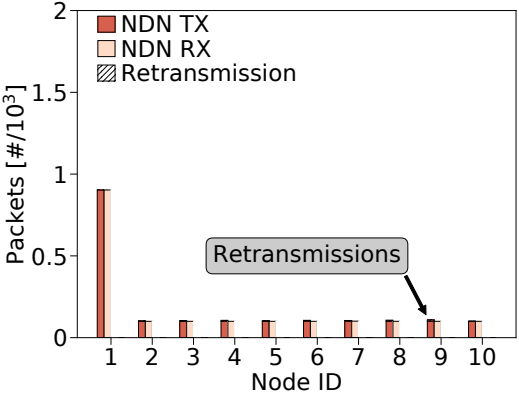

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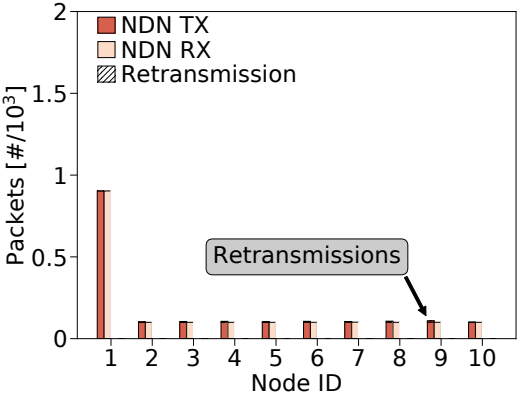

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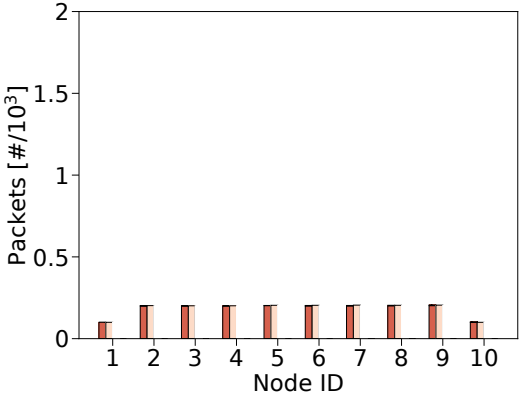

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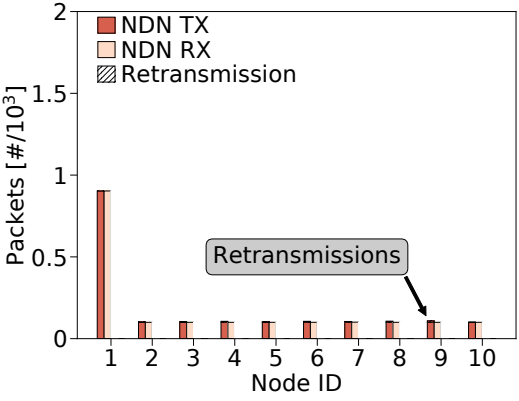

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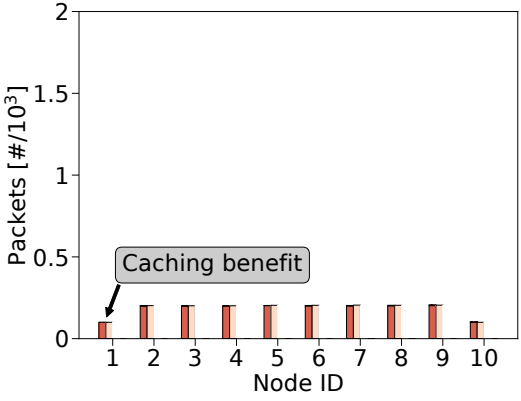

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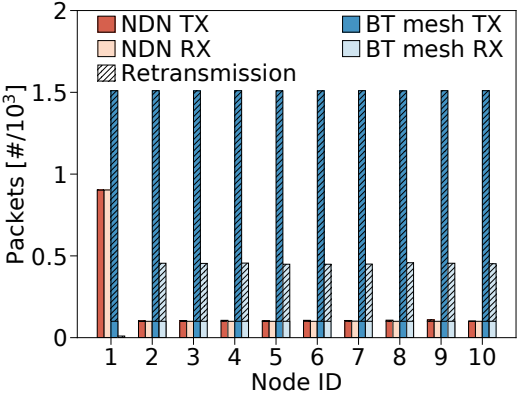

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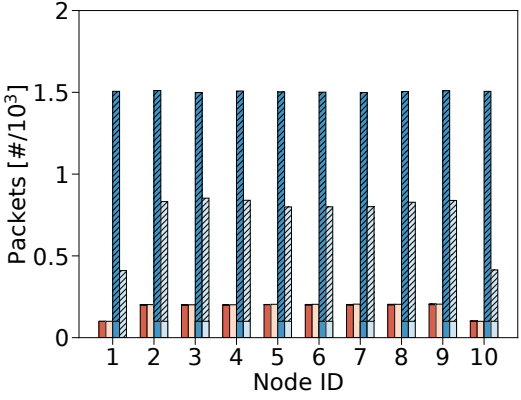

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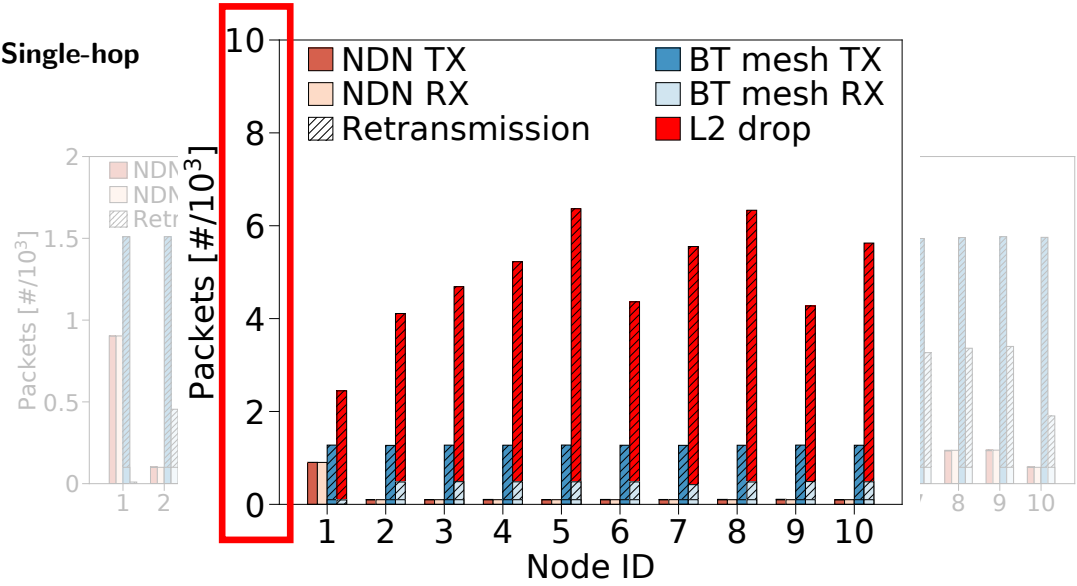

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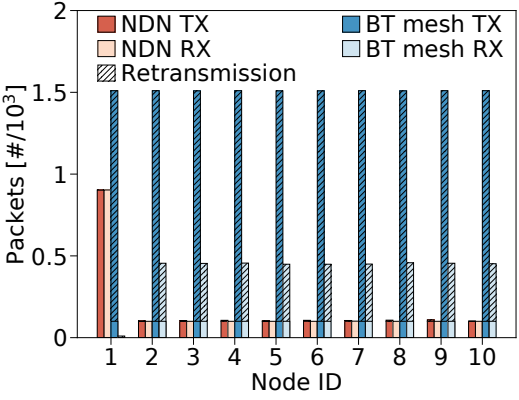

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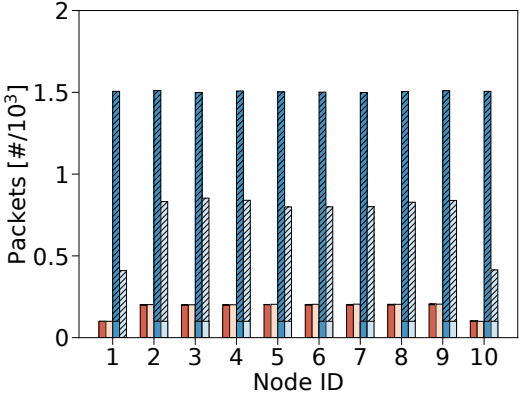


Redundant replications in BT mesh flood the medium with packets

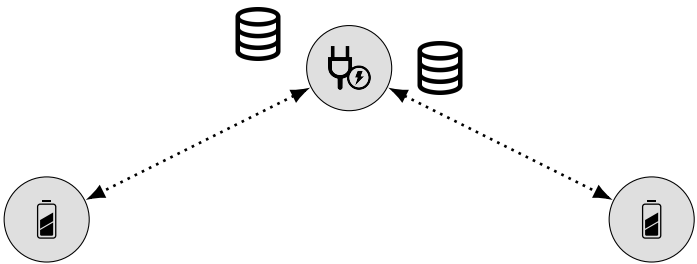
Outlook how ICN can benefit from BT mesh concepts

Low-power Friendship Feature in BT mesh

- Integrate battery driven nodes by coupling low-power and friend node
- Friend allocates **one** queue for **one** low-power node holds messages
- Low-power node sleeps and notifies friend on wakeup
- Friend delivers messages and **drops** them

Active Node

Establish



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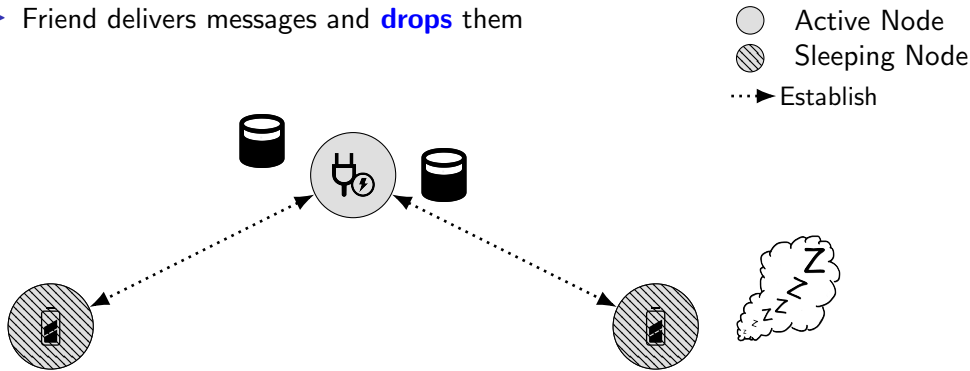

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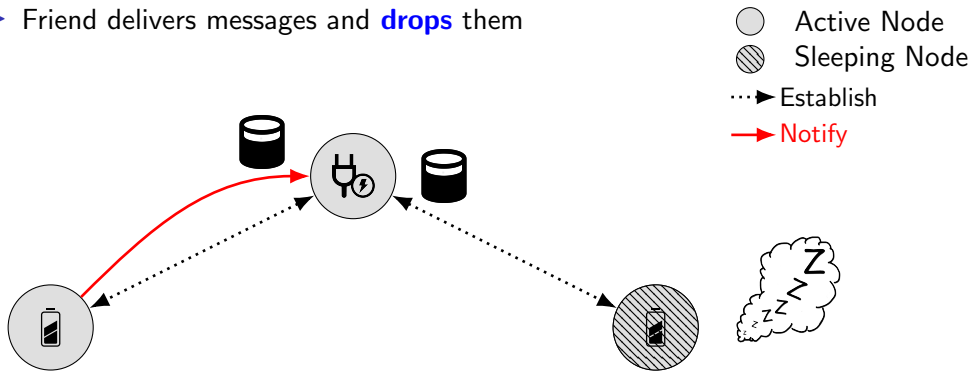

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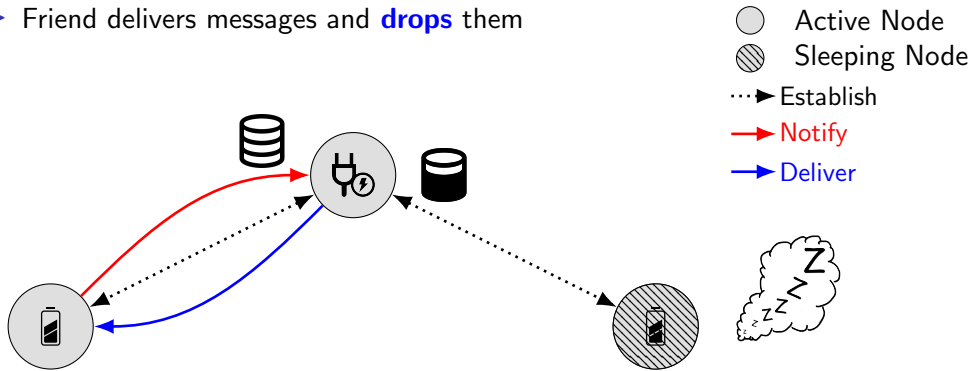
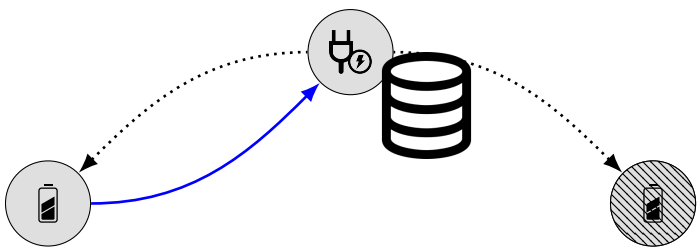


Use Friend as Deputy Cache in ICN

Friend requests low-power node

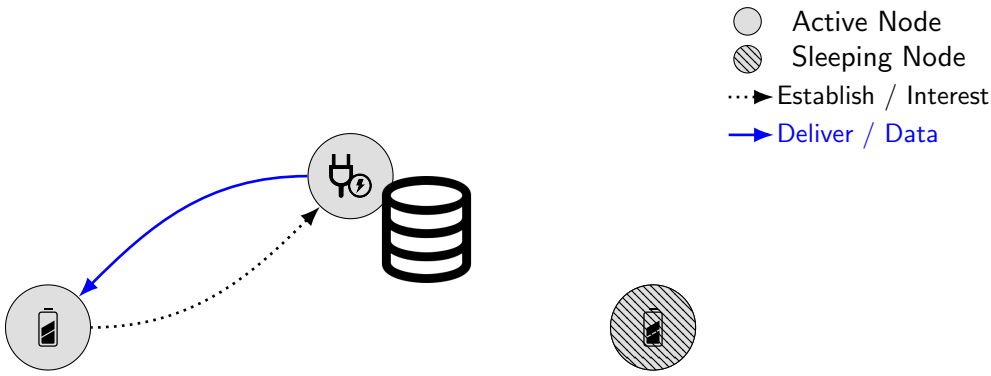
- Establish PIT state by *long-lived Interest*
- Low-power node answerers on wake-up
- Alternatives: HoPP, Interest Notification, ...



Use Friend as Deputy Cache in ICN

Low-power node requests friend

- Low-power simply sends Interest
- Sleep and retransmit request on next device wake-up



Conclusion

Comparative analysis if BT mesh is an ICN

Addressing has analogy but caching is missing

Experimental evaluation in different IoT deployments

Flooding and replication degrades network performance in BT mesh

Applicability for real-world installations

Full vertical BT mesh stack covers all aspects

Synergies by combining principles of BT mesh and ICN

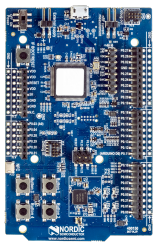
Potential improvements by adopting low-power feature in ICN

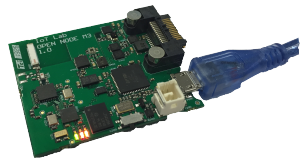
BS 1: Testbed Deployment

Parameters

- 4 replications on each node
- 20 ms advertisement interval
- 3 advertisement channels
- 4 Interest retransmits at max.
- 1 s retry interval & 10 s Interest t/o
- L2 ARQ and CSMA/CA

... default parameters where possible!



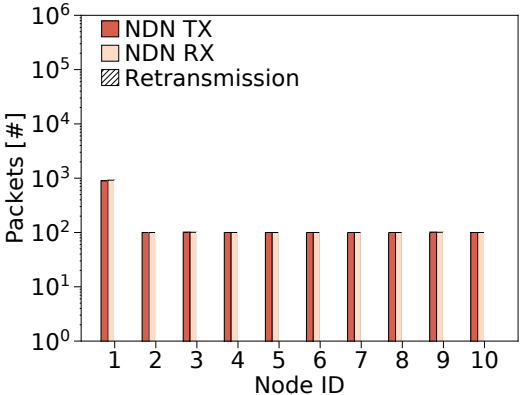


RIOT

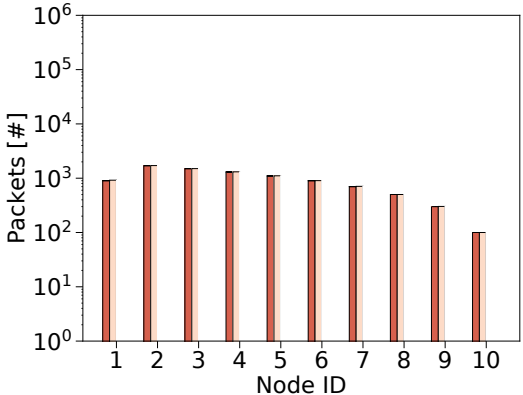
CCN-lite

BS 2: Traffic Load: Many-to-One

Single-hop



Multi-hop



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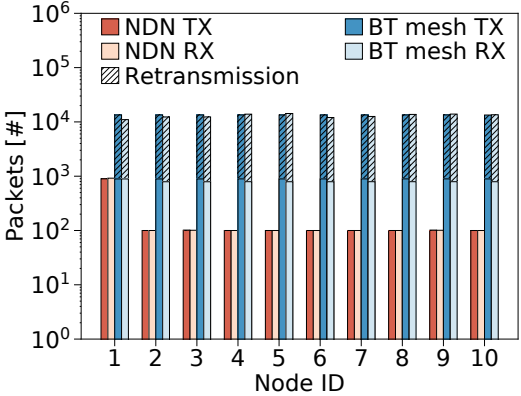

Multi-hop