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OPPORTUNISTIC ROUTING TOWARDS MOBILE SINK NODES IN BLUETOOTH MESH NETWORKS

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Research Goals

RQ1: Evaluate Bluetooth Mesh (BTMesh) as a viable technology for collecting data from WSNs using a mobile sink that sporadically connects to some of the nodes.

RQ2: Evaluate if we can increase energy efficiency with a slightly modified version of BTMesh that we propose.

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Mobile Sinks / Mobile-Hubs:

UAVs/Drones - data collectors

RQ2: Evaluate if we can increase energy efficiency with a slightly modified version of BTMesh that we propose.

Data Collection

- Sensors and other devices in the Internet of Things (example: temperature and humidity sensors)
  - data may be collected to be stored and processed on a cloud service
- Data Collection by drones or smartphones (*Mobile Hubs/Sinks*) by:
  - connecting to each sensor/network device; or
  - connecting to a subset of the sensor/network devices in a Mesh network, capable of forwarding data from other nodes

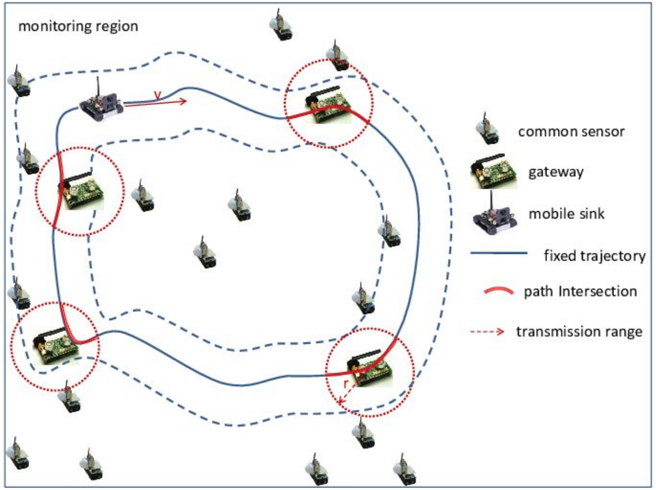

Fig. A: Monitoring network with sensors, gateways and mobile sinks. Xu e Liang (2011) [1]

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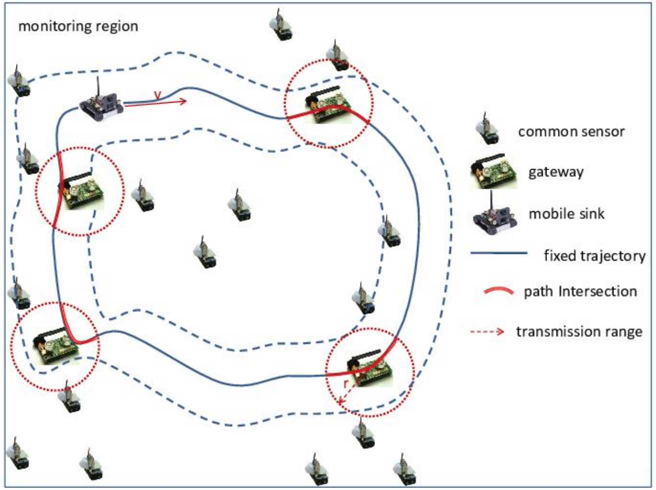

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Motivation

- Vacant land is often a place of pest spread (dengue/chikungunya) from the Aedes Aegypti mosquito
- Using fleets of drones (quadcopters) and Mesh networks on the ground
- Monitoring soil moisture or presence of small animals (rats, etc), that are detected and sensed by a mesh network on the ground
- Using Bluetooth Mesh could be a good option
- Faster data collection with fleet of drones that coordinate their flying

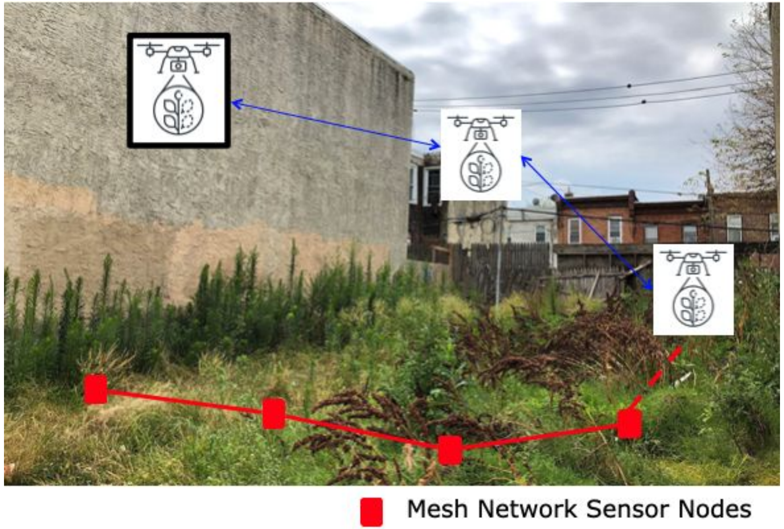

Fig. A: Motivation - vacant land illustration

Bluetooth Mesh

- Network protocol based on BLE (Bluetooth Low Energy)
- Important concepts:
  - **Friend Nodes (FNs)** - usually connected to a power outlet or a large battery, may receive messages on behalf of the LPNs
  - **Low Power Nodes (LPNs)** - low energy consumption, don't operate with the radio always on like the FNs, and request to their FN messages received on their behalf
  - **Relay Nodes** - relay network packets
- Relatively new technology (specification finalized in 2017) and has compatibility with most commercially available smartphones
- **Lower energy consumption with friend nodes**

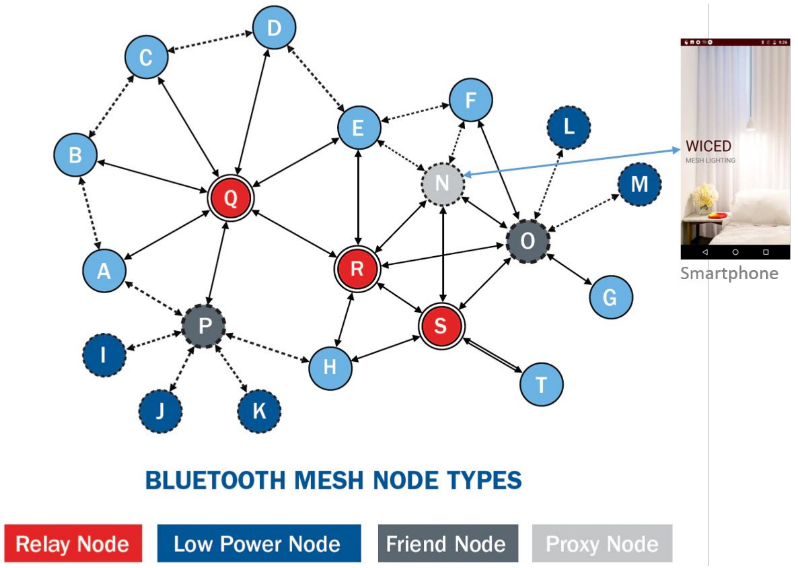

Fig. B: Bluetooth Mesh Network. Source: cypress.com

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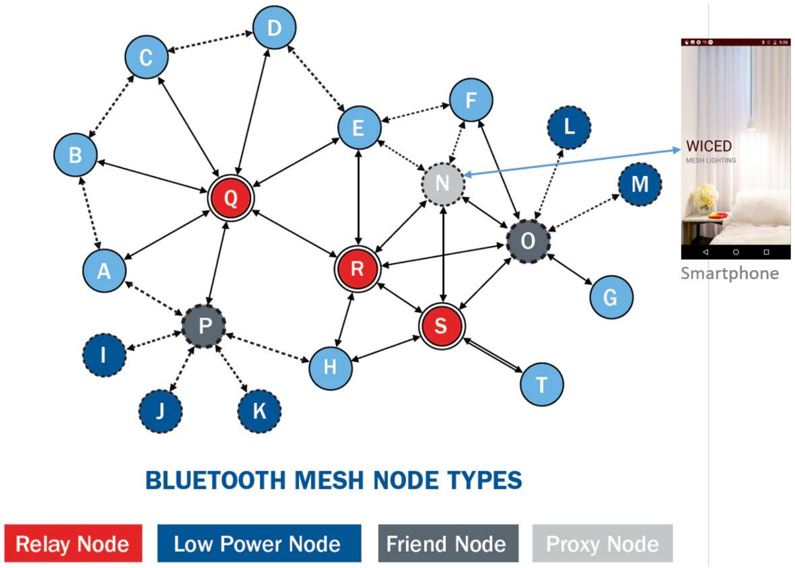
- **Energy consumption can be further improved with slight modifications**



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Application

Definitions:

- All Friend Nodes are Relay Nodes
- Low Power Nodes and Friend Nodes don't move
- Mobile Hub/Sink is always moving and may connect to any network node
- FNs are not added or removed

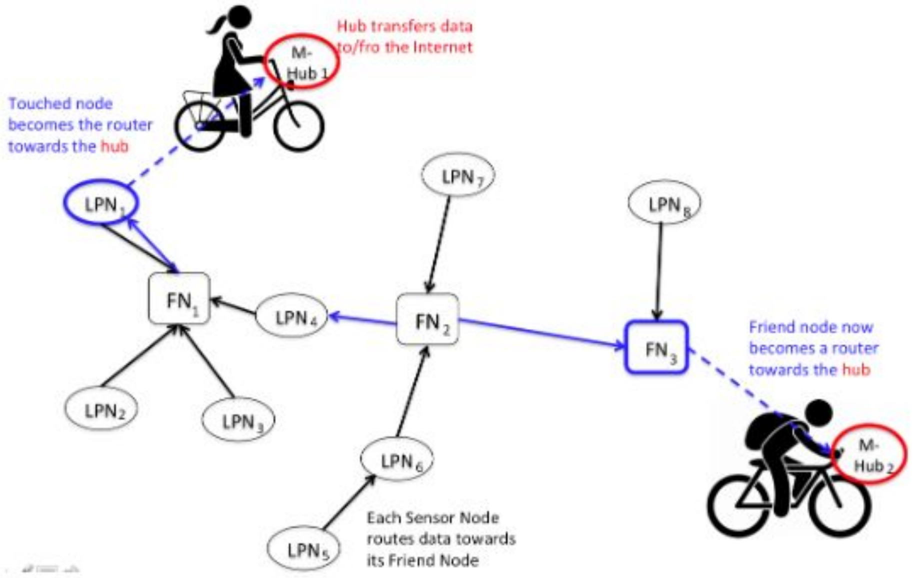

Fig. 1: mesh network with 11 nodes and 2 Mobile-Hubs

Single Mobile-Hub application

- Mobile-Hub moves broadcasting a Discovery packet, one time per second
  - Relay nodes that receive this packet retransmit it if possible.
  - Any recipient that has data to be sent to the Mobile-Hub sends the data towards it.

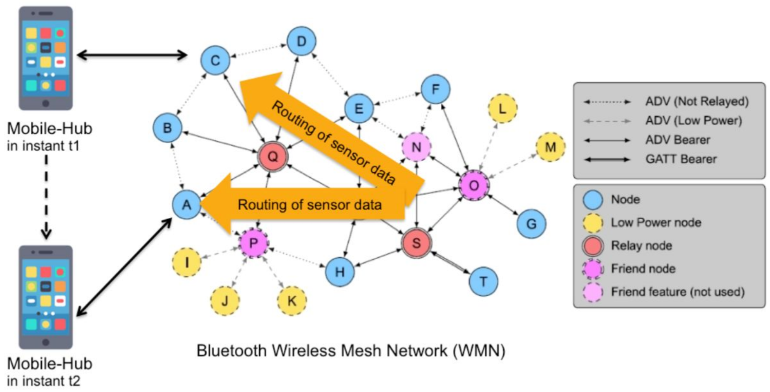

Fig. 2: Sample Bluetooth Mesh with a smartphone collecting data in two different instants and position. Instant t1=> connected to node C; instant t2=> connected to node A

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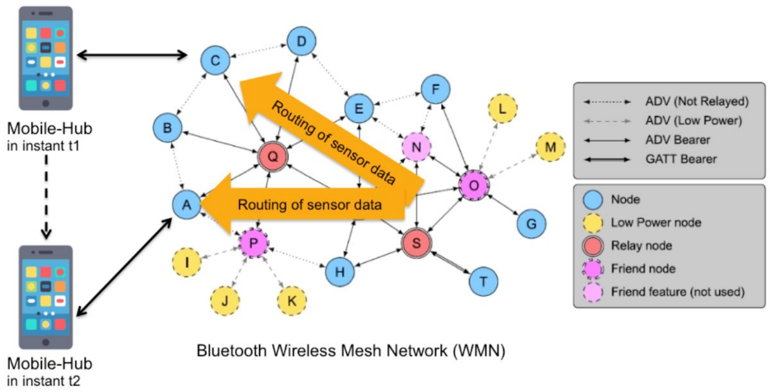

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The routing algorithms we propose (MAM-0 & *MAM-Δ*) affect this step. They are simple extensions to Bluetooth Mesh.

Bluetooth Mesh Relay (BTM-R) / Flooding

- Uses Bluetooth Mesh default Relay behavior:
  - Forwards the message if it has not been relayed recently (using an LRU message cache).
  - Stops relaying it if TTL>126.
  - Results in duplicate packets arriving at the Mobile-Hub (and more energy consumed when compared to the algorithms we propose).

MAM-0 / Last Known Route

- Our first try to improve Bluetooth Mesh default Relay algorithm (i.e. BTM-R) for data collection:
  - Store, in every node, the last node from which it received a Discovery Packet from Mobile-Hub.
  - In principle, this isn't good, as the Discovery Packet is broadcast using flooding, and we could use longer routes with this last known node approach.
  - The Mobile-Hub no longer received duplicate packets.

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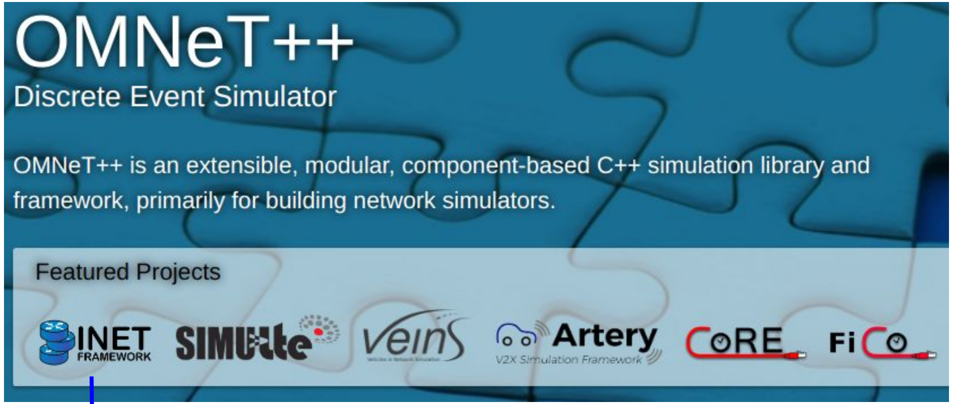
  - In principle, this isn’t good, as the Discovery Packet is broadcast using flooding, and we could use longer routes with this last known node approach.
  - The Mobile-Hub no longer received duplicate packets.
  - **Worse results than BTM-R**

MAM-Δ / Reactive route with least hops

- Similar to MAM-0's idea of establishing a route to the Mobile-Hub, we considered the number of hops to define which nodes are closer to the Mobile-Hub.
- As the Mobile-Hub is in movement, it's necessary to have a timeout so that the routes update over time.
- We created a Delta (Δ) parameter, which is a expiry time in milliseconds that, after expired, makes it so that the next Discovery Packet received by the node updates the closest node regardless of the number of hops to the Mobile-Hub.

Simulating data collection in OMNET++

- OMNET++ Discrete Event Simulator
- **INET Framework** (model suite for wired, wireless and mobile networks).
- Does not implement BLE or Bluetooth Mesh
  - Our implementation was based on the 802.15.4 (LR-WPANs) protocol, present in the framework



Model suite for wired, wireless and mobile networks

Simulations

This work:

i) used OMNET++ / INET for simulations/experiments.

ii) extended the INET framework, adding Bluetooth Mesh functionality.

iii) used a fixed map/network (named MAM50), with 50 nodes.

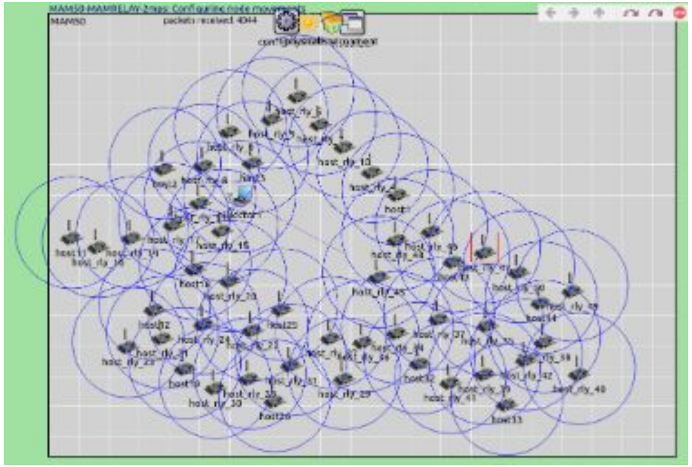
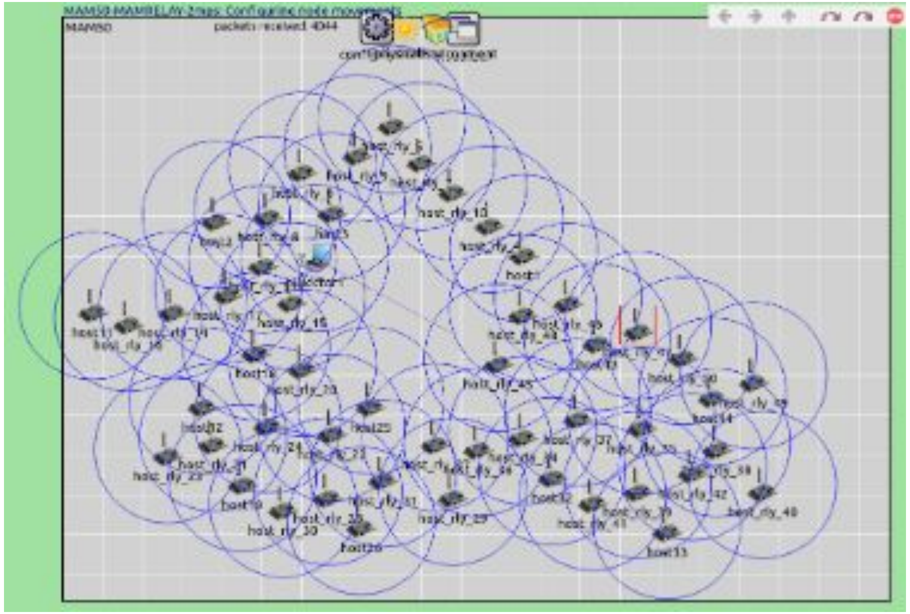


Fig. 3: MAM50 - 50 nodes and a Mobile-Hub.

Mobile-Hub movement

O Mobile-Hub moved at a constant speed of 14 m/s, in a circular trajectory with a 400 meters radius.



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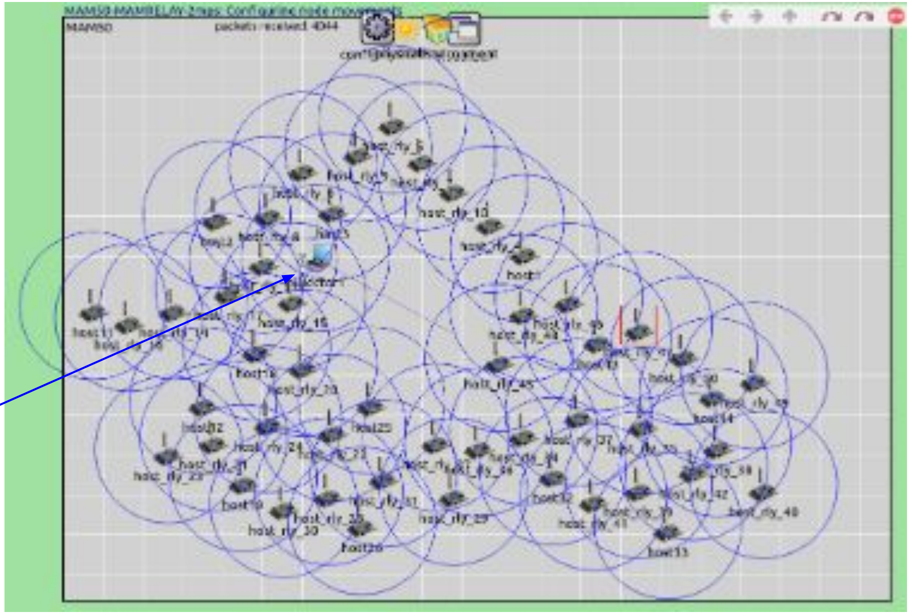

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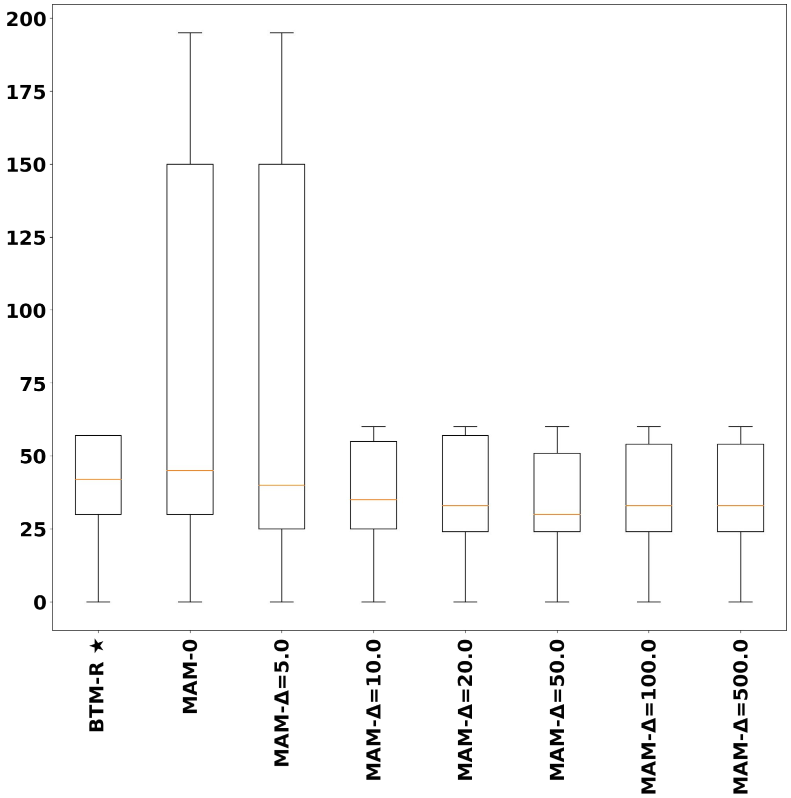
Collected metrics

- End-to-end delay: time (milliseconds) from the moment a node sends the data until it reaches the Mobile-Hub.
- Energy draw: (in Joules) of all network nodes.
- M-Hub received packets: quantity, in bytes, of data that the Mobile-Hub collected.
- M-Hub delivery rate: (%) of packets delivered to the Mobile-Hub.

MAM (50 nodes) - End-to-end delay

- Median delay for all MAM-Δ was lower than BTM-R, while MAM-0’s was higher.
- MAM-0 doesn’t consider the number of hops and may take longer routes, consistent to those results.

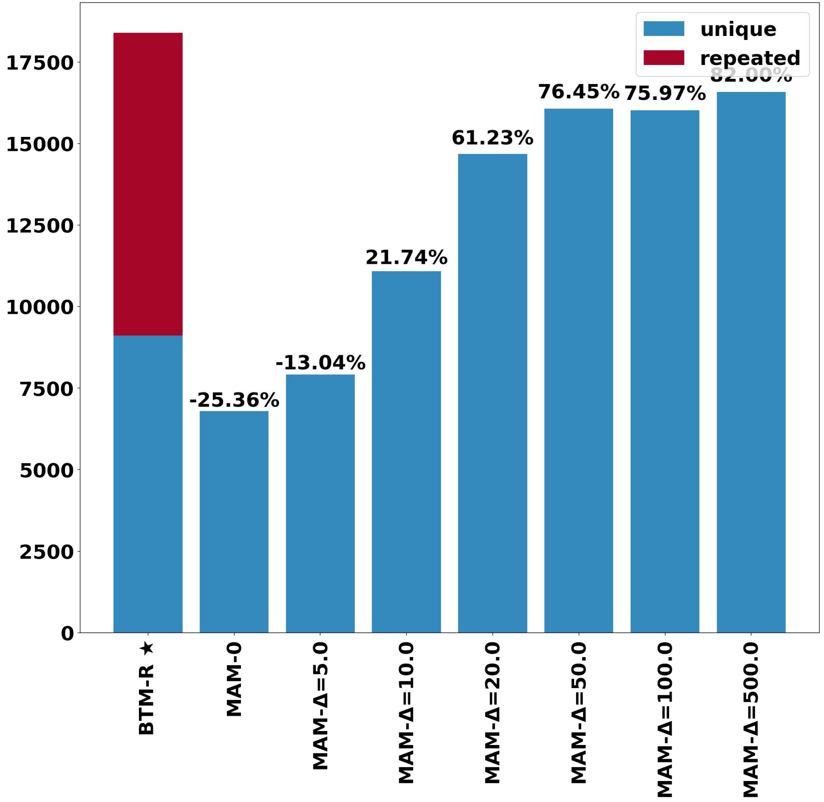
Fig. 4: End-to-end delay from sensors to Mobile Hub in milliseconds (14m/s)



MAM (50 nodes) - M-Hub Received Packets

- Bluetooth Mesh received a lot of duplicate packets.
- For Δ>5, MAM-Δ received more unique packets than BTM-R, up to 82% more.

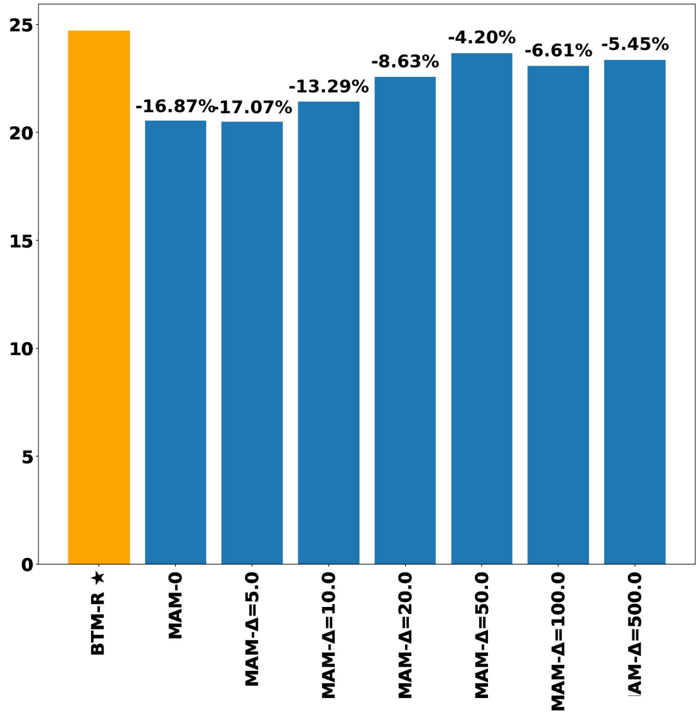
Fig. 5: **M-Hub Received packets in bytes (14m/s)**



MAM (50 nodes) - Energy Draw, in Joules

- All simulated variations consumed less total energy than BTM-R, but this has to be analyzed considering the amount of collected (unique)data.
- MAM-Δ=500, **5.45% less energy** was spent, and as shown by Fig 5, **82.00% more data** was collected.

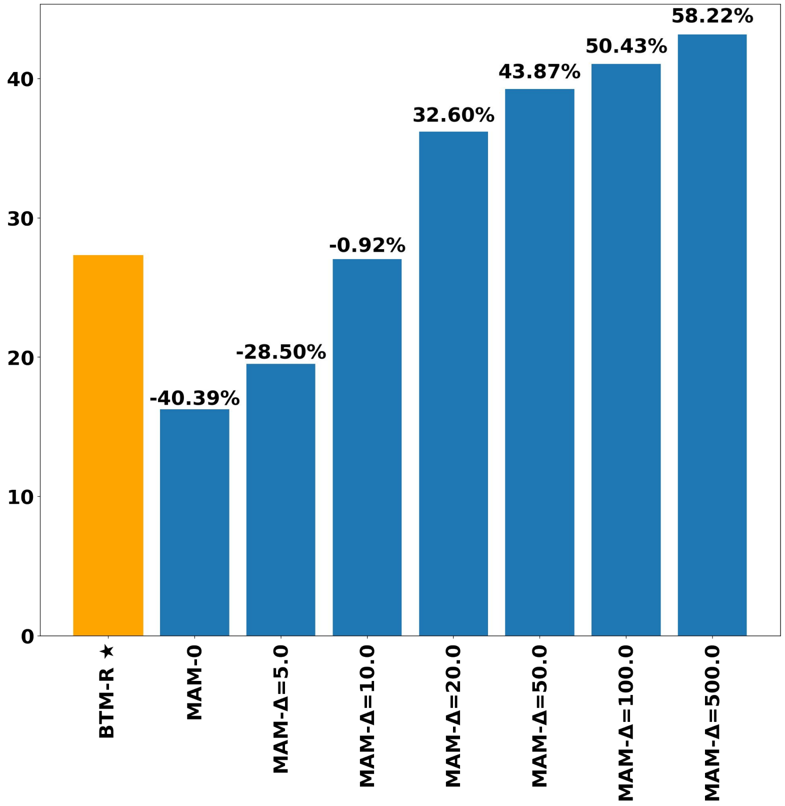
Fig. 6: Energy draw (14m/s)



MAM (50 nodes) - M-Hub delivery rate, in %

- For Δ>10, the delivery rate was higher than BTM-R's.
- 58.22% higher with Δ=500, with ~45% delivery rate, while BTM-R's was ~27%.

Fig. 7: M-Hub delivery rate (uniqueDataReceived/uniqueDataGenerated) in % (14m/s)



MAM (50 nodes) - Limitations

1. We only simulated with a single map and topology, with 50 nodes. Interesting results, but limited to this configuration.
2. Certain characteristics like LPN/FN proportion as well as speed and time the Mobile-Hub stays connected were not varied.

Other limitations

1. OMNET++/INET does not implement BLE (Bluetooth Low Energy) nor Bluetooth Mesh.
   a. Our implementation was based on the 802.15.4 (LR-WPANs) protocol, present in the framework, using UDP and CSMA/CA
   b. 802.15.4 collision avoidance is different than Bluetooth Mesh's simpler frequency hopping

2. We haven't varied the interval in which the Discovery Packets were sent by the Mobile-Hub.

Future Work

- Test with multiple, randomly generated maps and network topologies
- Field tests using microcontrollers (ESP32) and a UAV as Mobile-Hub
- GRADYS project - LAC/PUC-Rio

Q&A

Thank you!

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