A Scalable Approach for Reliable Downstream Data Delivery in Wireless Sensor Networks

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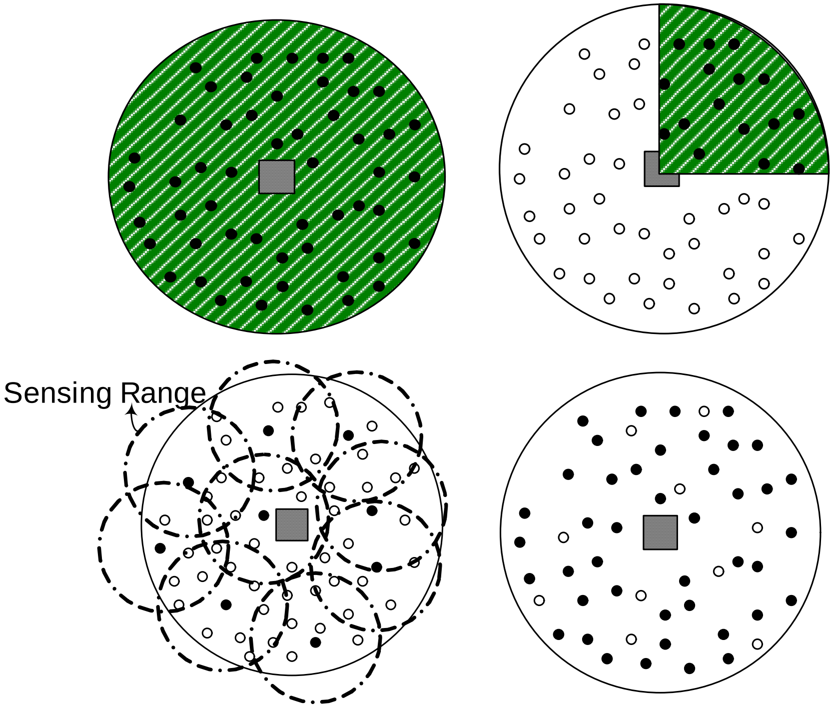
Introduction

- WSN is a multi-hop wireless network consisting of
  - Sink: central coordination entity that sends queries
  - Sensors: monitor phenomena and reports to sink
- Applications – military, environment monitoring, biomedical, other civilian applications
- ☞ Critical applications might require communication reliability
- Reliability cannot be taken for granted
  - Random wireless losses
  - Broadcast storm
  - Reverse path contention

Downstream Reliability in Sensor Networks

Problem Definition

- A sink should deliver data to static sensors reliably
- Message considerations
  - Queries, Query-data, Control Code
- Scope of delivery considerations
  - Delivery to an entire area
  - Delivery to a sub-area
  - Delivery to the minimum # of nodes
  - Delivery to p% of nodes
- Environment considerations
  - Limited energy, low bandwidth, high node density, frequent node failures, no global node identification



Efficient loss recovery solution that addresses the above considerations

Design Preliminaries

- Packet forwarding
  - How to forward packets?
    - In-sequence [PSFQ] or out-of-sequence forwarding
    - ☞ Out-of-sequence forwarding to utilize underlying capacity better
- Loss detection
  - How to request for lost packets?
    - ACK or NACK
    - ☞ NACK to avoid ACK implosion
- Loss recovery
  - Who and how to recover losses?
    - Non-local or local, designated or non-designated
    - ☞ Local, designated scheme to decrease contention with packet forwarding

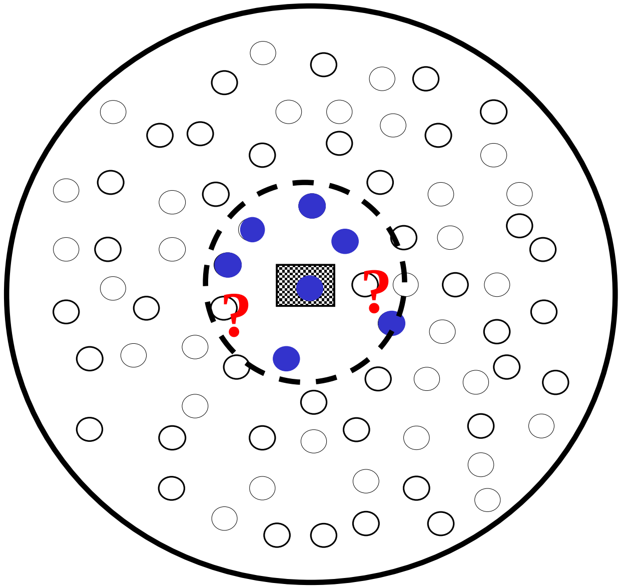
Design Challenges

- Single packet delivery
  - Reliably deliver single packet messages or small size messages
- Loss Recovery
  - Determine an efficient recovery structure to recover losses
  - Determine when to request and recover lost packets
  - Prevent error propagation
- Reliability variants
  - Address the different reliability semantics

GARUDA: Accommodates the different considerations in a unified fashion while addressing the above challenges

Single Packet Delivery : The Problem

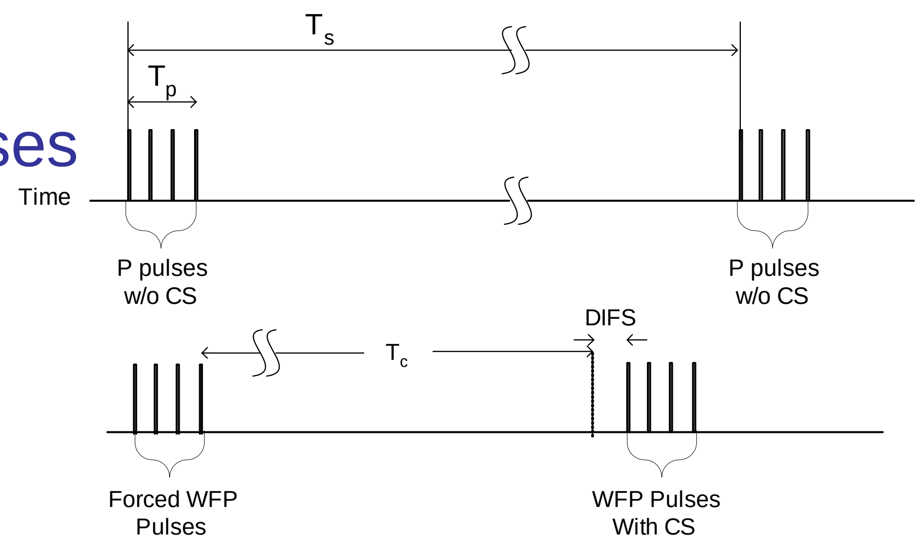
- For small messages or single packet messages
  - All the packets in a message can get lost
    - NACK cannot request for lost packets
  - ACK scheme results in ACK implosion
- Once the first packet reliability is supported, size of message is known
  - ☞ NACK can be used for requesting lost packets



To realize a scheme that supports first packet reliability

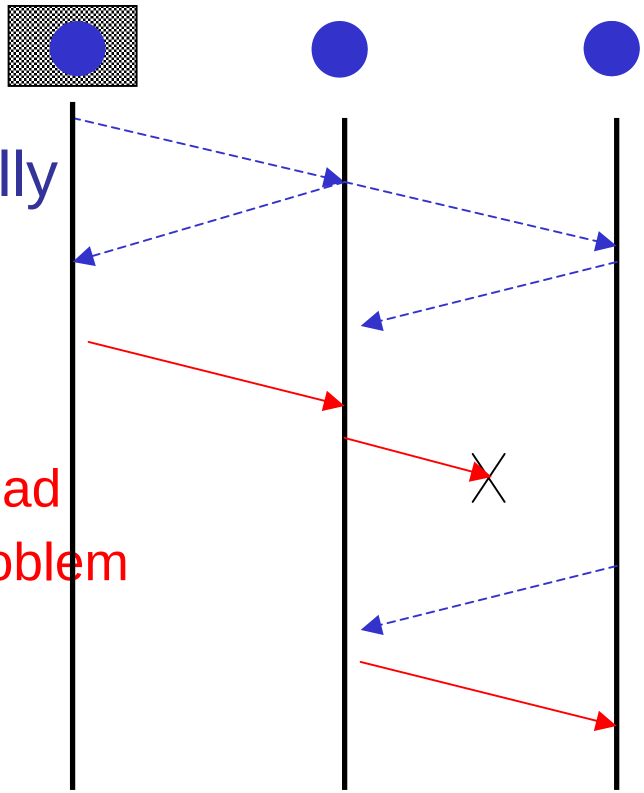
WFP Overview

- WFP (Wait-for-First-Packet) pulses
  - Used only for first packet reliability
  - Short duration pulses
  - Single radio
  - Advertisement of incoming packet
  - Negative ACK
  - Simple energy detection
- Different types of WFP pulses
  - Forced pulses
  - Carrier sensing pulses
  - Piggybacked pulses



WFP Mechanism and Merits

- A sink sends WFP pulses periodically
  - Before it sends the first packet
  - For a deterministic period
- A sensor sends WFP pulses periodically
  - After it receives WFP pulses
  - Until it receives the first packet
- WFP merits
  - Prevents ACK implosion with small overhead
  - Addresses the single or all packets lost problem
  - Less energy consumption
  - Robust to wireless errors or contentions



Addressed single packet reliability

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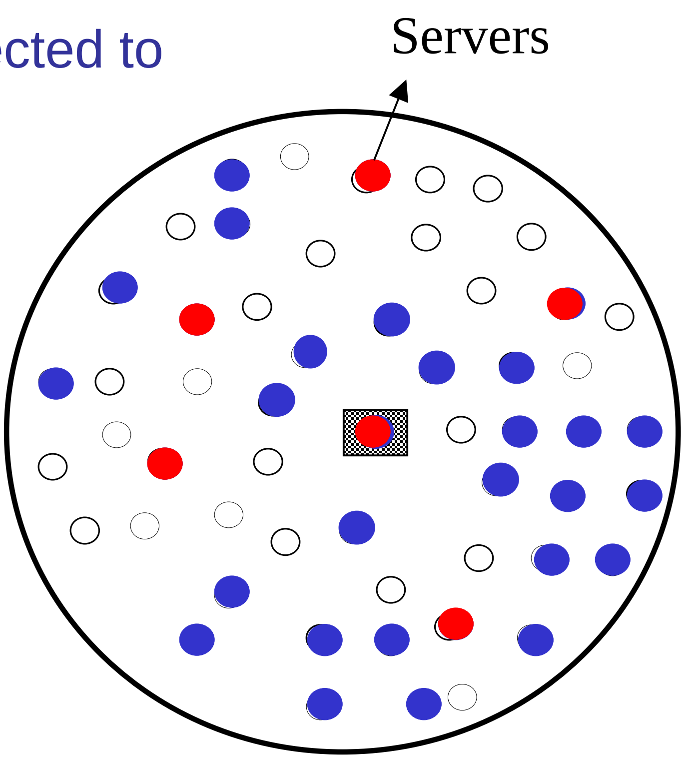
Loss Recovery : The Problem

- Designation of recovery servers
  - Construct the recovery server structure
    - Minimizes the number of recovery servers
    - Low overhead and feasible designation
- Efficient loss recovery
  - Request for losses
    - Least possible contention with forwarding
    - Reduces the latency for recovery
- Error propagation
  - Out of sequence with NACK results in NACK implosion
    - Prevent propagation of NACKs

Recovery Server Designation

- Minimize the set of recovery servers
- Ideal solution: Minimum Set Cover (MSC)
  - Minimize the number of blue nodes selected to cover all white nodes
  - Infeasible because of per-packet basis
- GARUDA: Distributed Minimum Dominating Set (MDS)
  - Approximation of MSC
  - Independent of loss pattern
  - Per message basis



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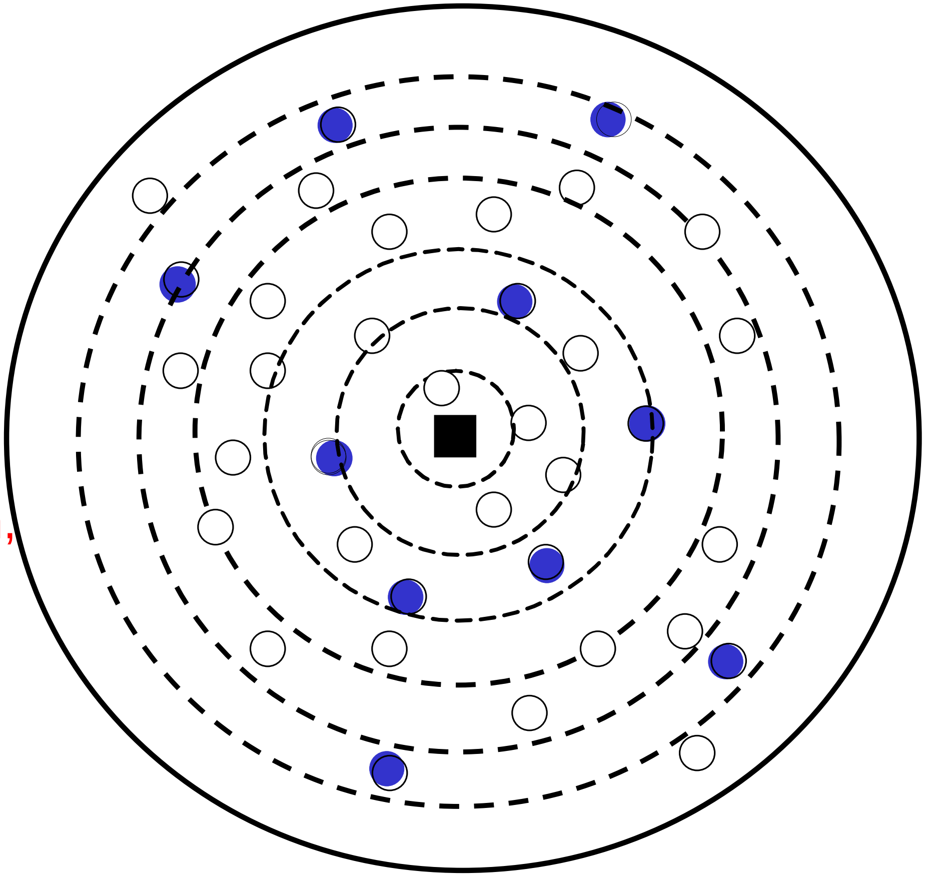
Core Structure

- Distributed MDS
  - Virtual bands constructed during the first packet flood
  - Nodes choose core nodes from every 3rd band
  - Adjacent nodes elected as core only if required
- Core Merits
  - Approximation of the ideal solution, MSC
  - Decentralized construction during the 1st packet delivery
  - Fault tolerant
  - Low maintenance overhead



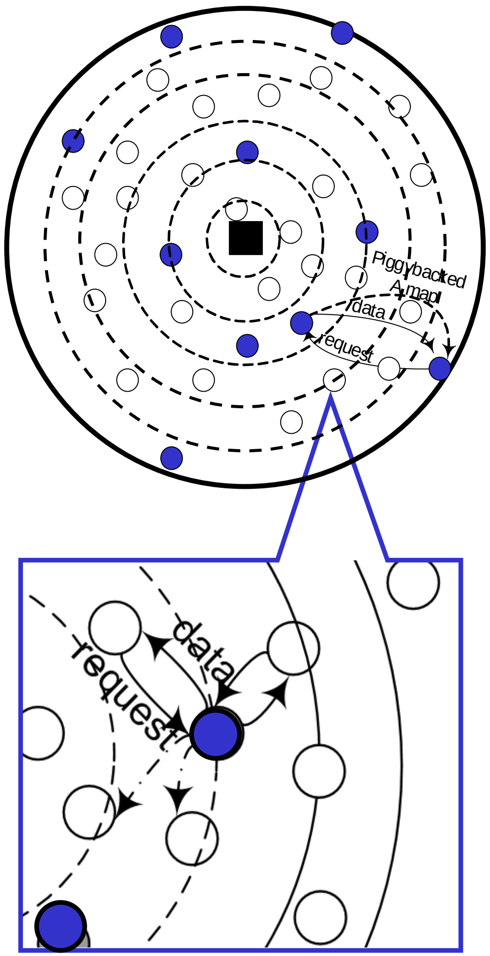
Efficient Recovery Structure

Recovery Structure Summary

- ✓ Single packet reliability
- ☞ Loss recovery
  - ✓ Efficient recovery structure
  - ☞ Efficient loss recovery
  - ✓ Error Propagation
- ✓ Reliability variants

Two-Phase Loss Recovery

- Minimize contention between loss recovery and data forwarding
- Two-phase loss recovery
  - Phase 1
    - Loss detection and recovery between core nodes
    - <u>At the end of phase 1, all core nodes receive all packets</u>
  - Phase 2
    - Loss detection and recovery between non-core nodes and its core node
- Two-phase merits
  - Reduces the contention between loss requests and data forwarding
  - Reduce redundant retransmissions by utilizing wireless local broadcast



Efficient loss recovery mechanism

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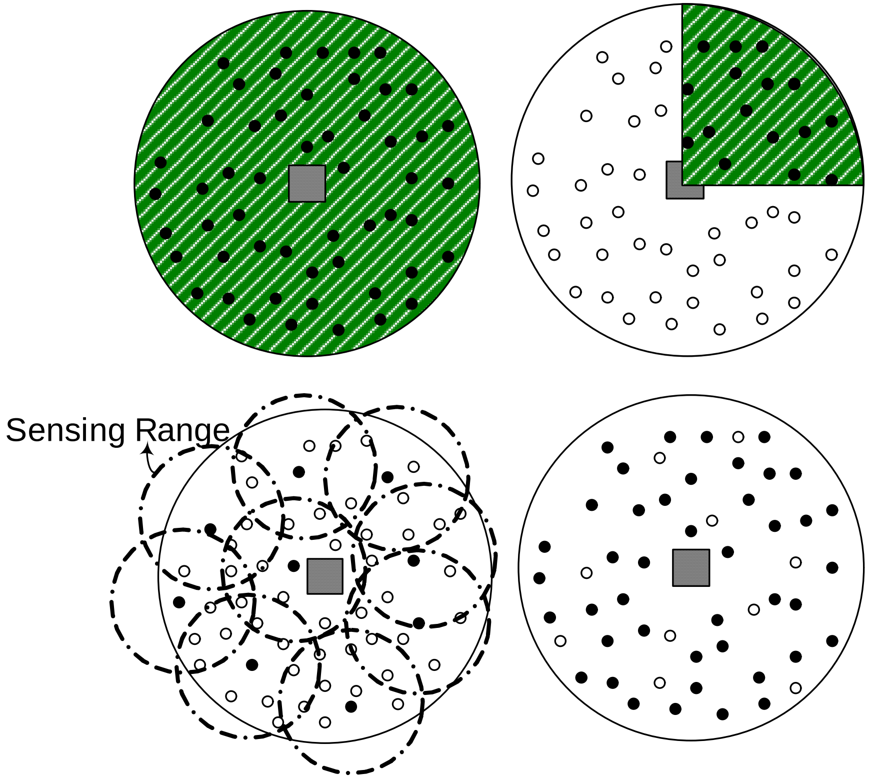
Loss Recovery Summary

- ✓Single packet reliability
- ✓Loss recovery
  - ✓Efficient recovery structure
  - ✓Efficient loss recovery
  - ✓Error propagation – Availability map
- ☞Reliability variants

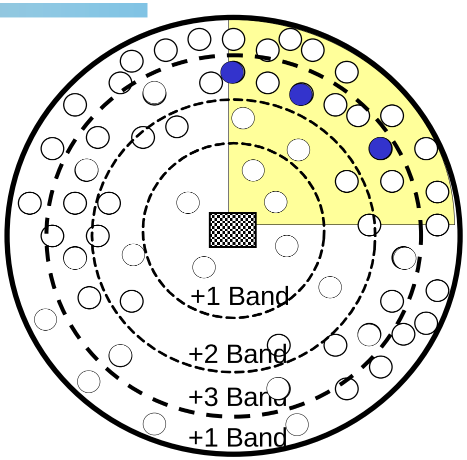
Variants : The Problem

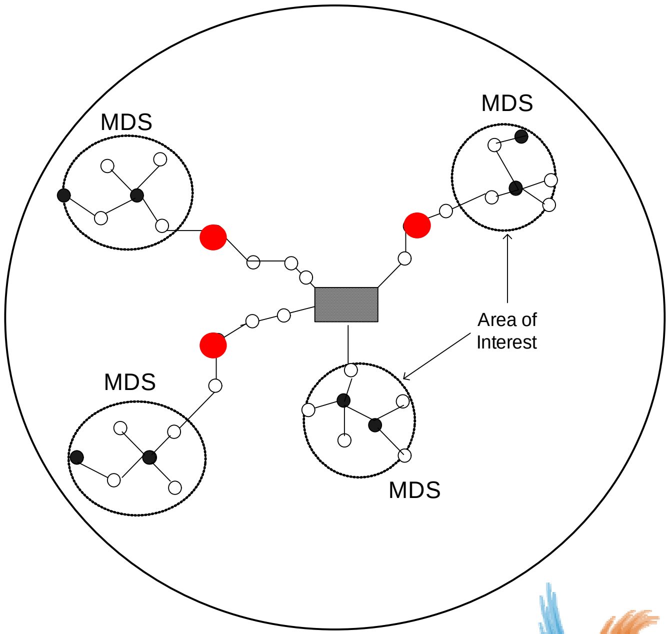
- How to address different types of reliability semantics
  - Reliable delivery within a sub-region
  - Reliable delivery to minimal set of sensors
  - Reliable delivery to probabilistic subset
- Candidacy to address reliability variants
  - Easy extension of GARUDA



Candidacy

- Candidacy
  - Candidates chosen during first packet flood
- Core construction
  - Candidates participate in core construction
- Once core is established, use basic GARUDA
- If disjoint regions from sink
  - Forced candidacy
- Candidacy merits
  - Unified framework





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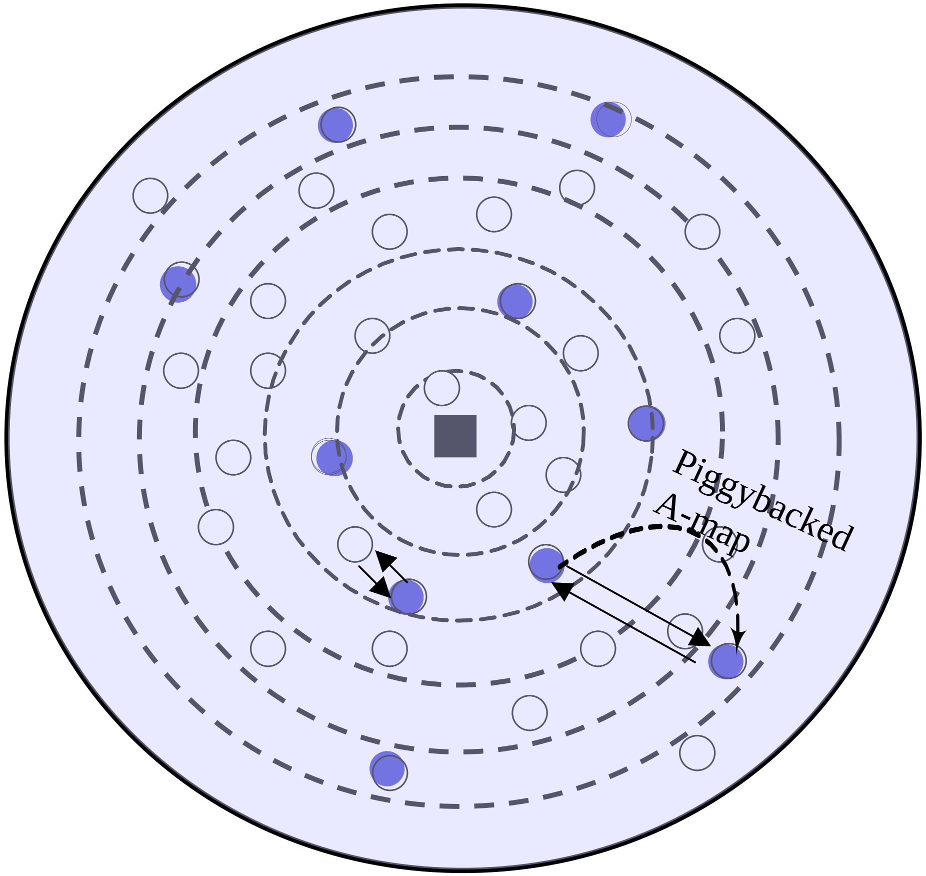
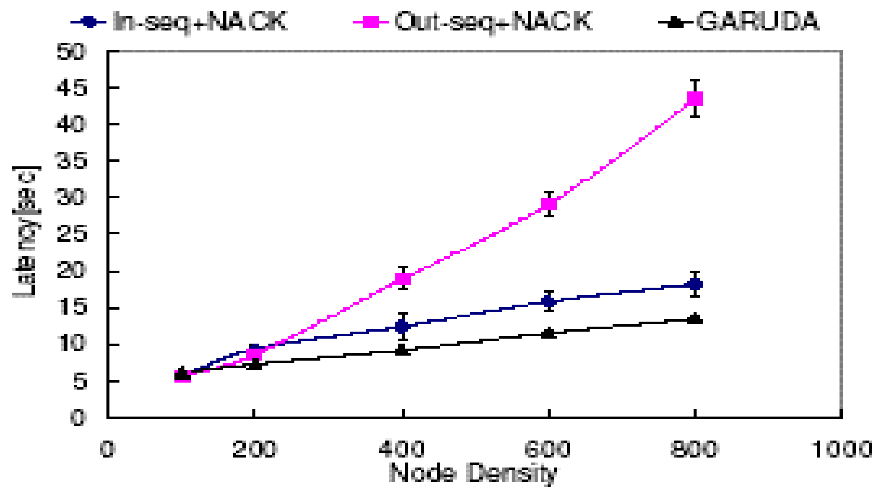
GARUDA Recap

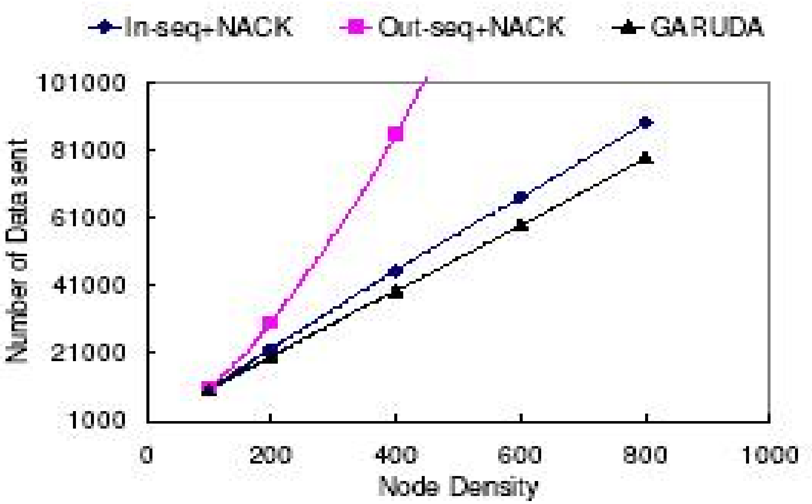
- ✓Single packet delivery
- ✓Candidacy
- ✓Core construction
- ✓A-map propagation
- ✓Two-phase loss recovery

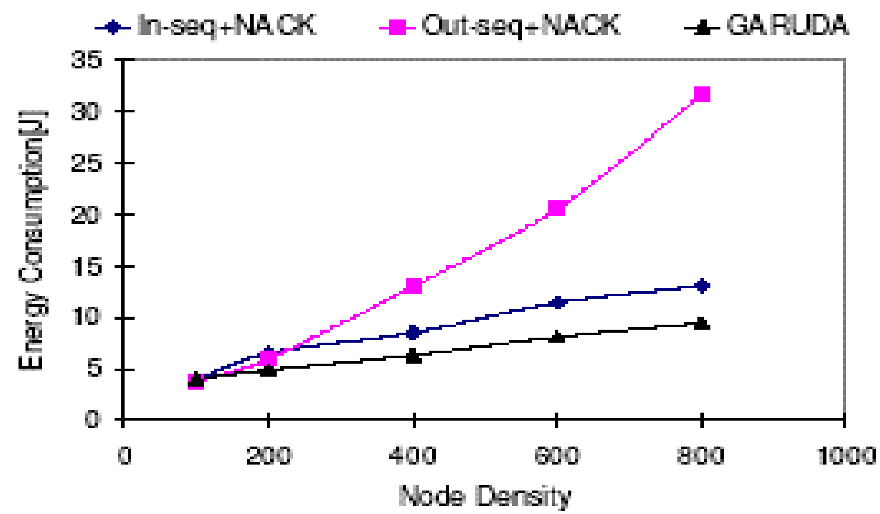


Performance Evaluation

- ns-2 simulator
- GARUDA performs better
  - Efficient core structure
  - Two-phase loss recovery
  - Availability map







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Conclusions

- Motivated the necessity for reliable delivery in sensor networks
- Presented a unified approach to handle message size considerations and scope of delivery
- Identified the ideal solution and the distributed approximation for ideal designation of recover servers
- Demonstrated the effectiveness of GARUDA
- For more details, please visit our group website:

http://www.ece.gatech.edu/research/GNAN/