An Experimental Study of Routing and Data Aggregation in Sensor networks

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In this paper

- We consider a hierarchically organized multi-hop network and do not assume the presence of any specially-equipped nodes
- We integrate node clustering with tree aggregation in the “iHEED” system
- We implement the iHEED system in TinyOS and evaluate it on Berkeley motes to show its effect on network lifetime

Outline

- Introduction
- System model
- The HEED protocol
- The iHEED system
- Evaluation of iHEED
- Concluding remarks

Introduction

- In sensor networks:
  - Nodes may be deployed and left unattended
  - Battery lifetime is limited
  - Radio communication is a major source of energy consumption

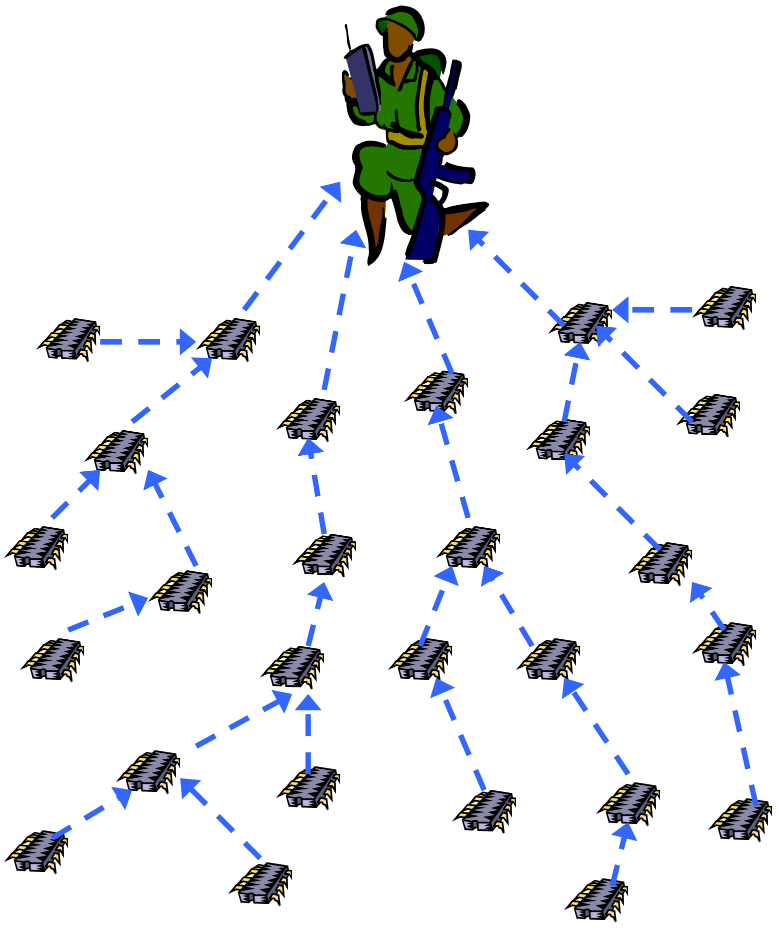
- Objective:
  - Reduce energy consumption to prolong the network lifetime

Energy-efficiency

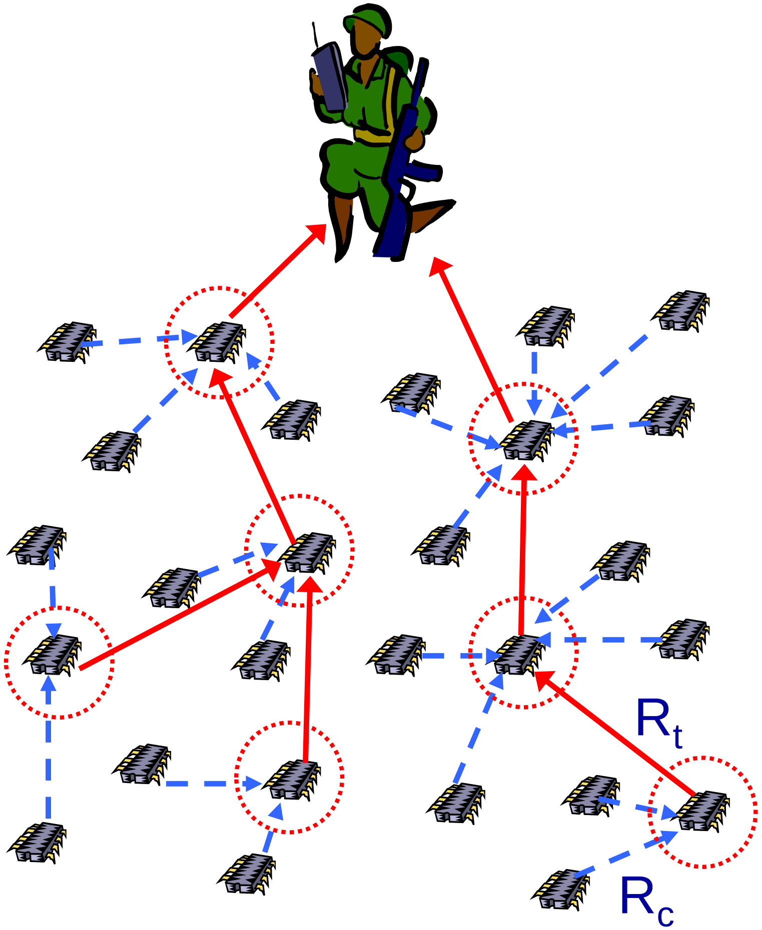
- Network lifetime:
  - The time until the first (last) node in the network dies
  - The time until the observer is disconnected
- Alternatives:
  - Node duty cycle
  - Redundant node deployment
  - Efficient topology management
- Our approach
  - Construct a hierarchical (clustered) network

Communication models

Flat topology



Hierarchical (clustered)



System model

- A set of *n* sensor nodes are dispersed uniformly and independently in a field

Network	ad-hoc, unattended, and no infrastructure support
Nodes	quasi-stationary, equally significant, location un-aware, and their transmission power levels are tunable
Application	Source-driven or data-driven with high load and opportunity for data aggregation

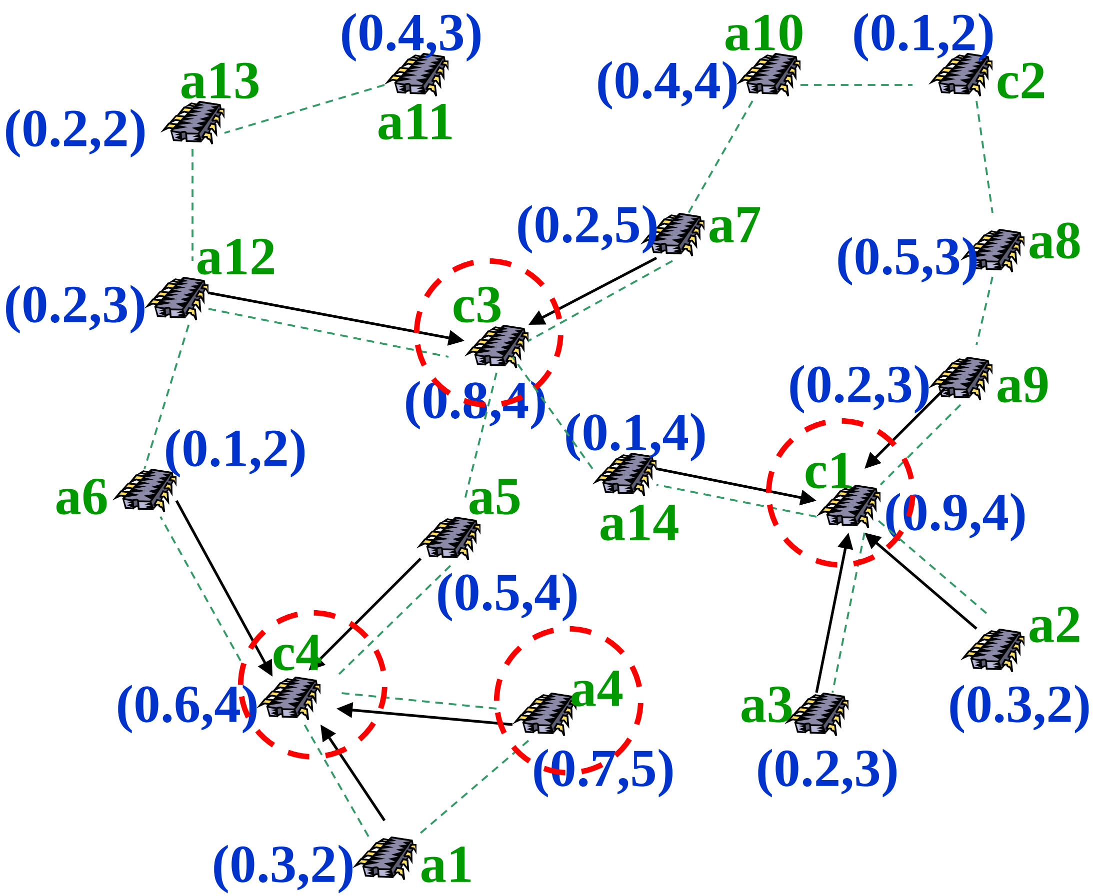
HEED clustering (Infocom'04, TMC'04)

- Initialization
  - Discover neighbors within cluster range
  - Compute the initial cluster head probability $CH_{prob} = f(E_r/E_{max})$

- Main processing
  - If received cluster head messages, choose one head with min. cost
  - If no cluster head message is heard, elect to become a cluster head with CH_{prob} .
  - $CH_{prob} = \min(CH_{prob} * 2, 1)$
  - Repeat until CH_{prob} reaches 1

- Finalization
  - If cluster head is found, join its cluster
  - Otherwise, elect to become cluster head

HEED example



(1) Discover neighbors

(2) Compute CH_{prob} and cost

(3) Elect to become cluster head

(4) Resolve ties

(5) Select your cluster head

HEED implementation (iHEED)

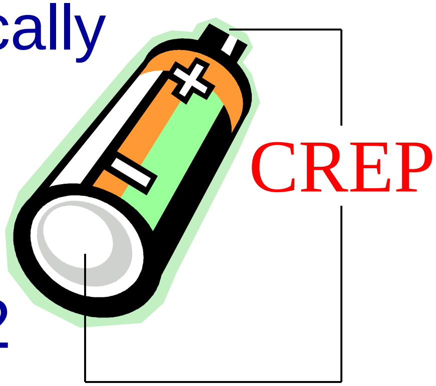
- Implement HEED in TinyOS
- Integrate clustering with multi-hop routing
- Application:
  - Data aggregation at a base station
  - Consider simple data aggregators, such as AVG, MIN, MAX, SUM, and COUNT
- Challenges:
  - Tracking the battery level
  - Handling node asynchrony

Hardware platform

- The Mica2 mote has a 7.38 MHz processor, while the Mica2Dot has a 4 MHz microprocessor.
- 128 KB program memory, 4 KB RAM, and 512 KB non-volatile storage.
- The radio is a Chipcon SmartRF CC1000, with 916 MHz frequency,
- FSK modulation with data rate 38.4 kBaud (19.2 Kbps) and Manchester encoding.
- Output power is digitally programmable by setting the PA_POW register.

iHEED: Computing residual energy

- Store a soft-state view of residual energy by
  - Using a Credit-Point (CREP) system
  - Decrementing the available points periodically

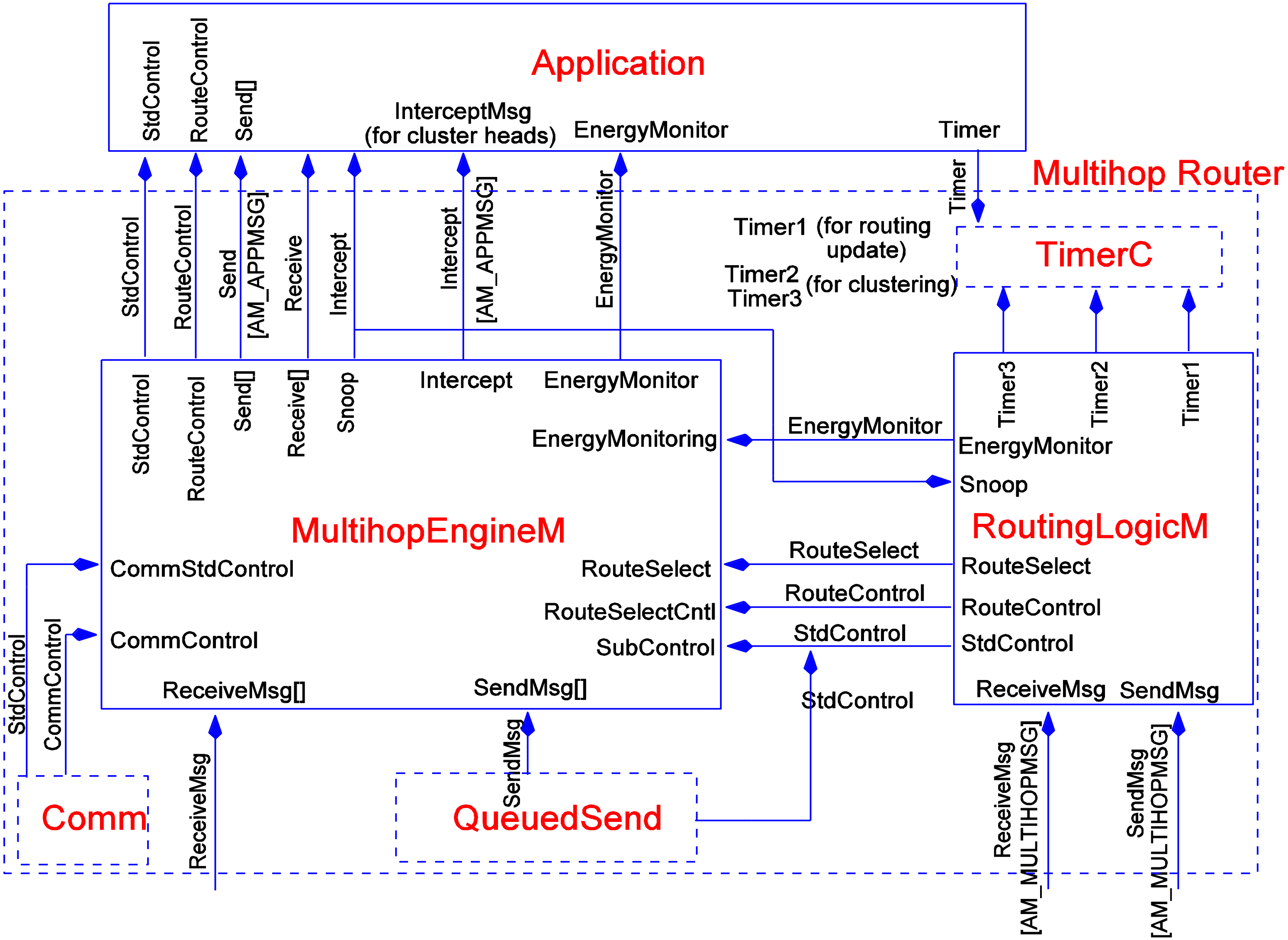


- Example: Two 1.5V AA batteries for Mica2
  - Given: packet size = 36B, bit time = 62.4 µsec
  - E_{max} = 2.2 A-hr x 3V x 3600 sec = 23760 Joule
  - E_{tx} (1 packet) = 16.8 mA x 3V x 62.4 µsec x 288 bits = 0.9 mJoule
  - E_{rx} (1 packet) = 8 mA x 3V x 62.4 µsec x 288 bits = 0.43 mJoule

iHEED: Handling node asynchrony

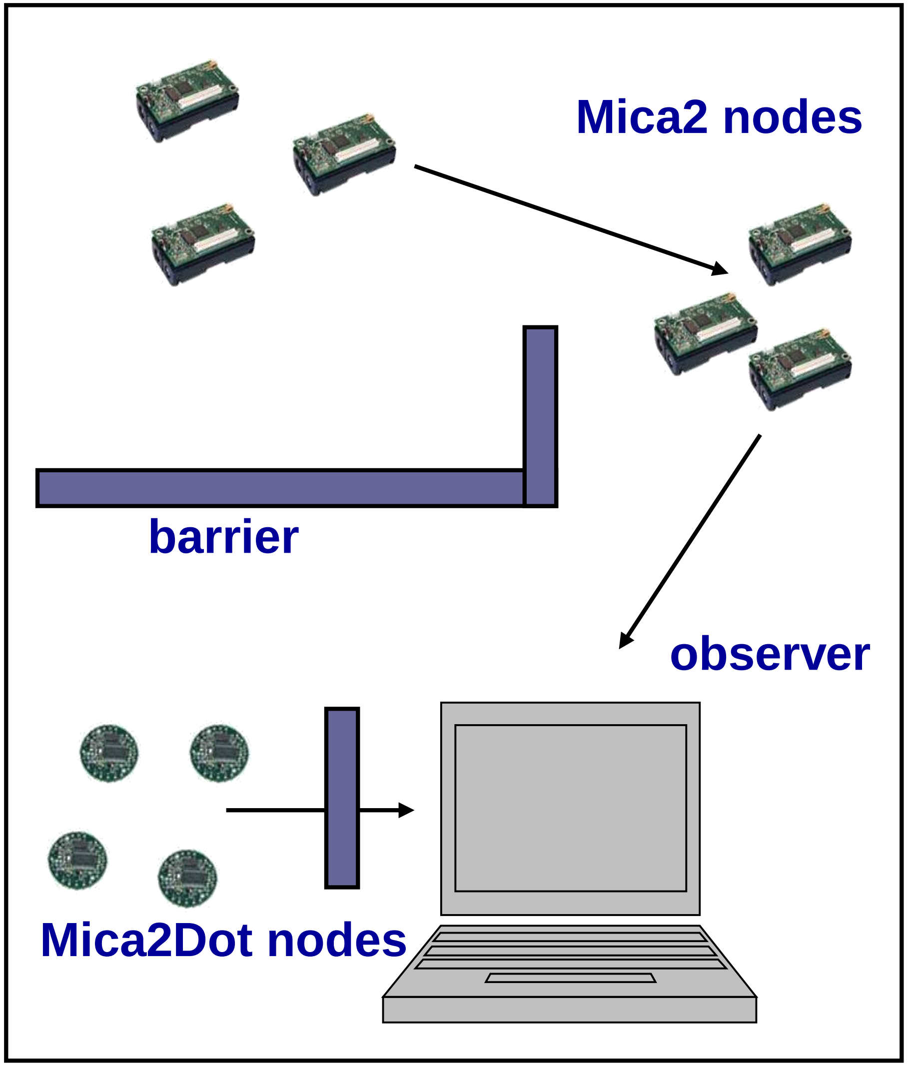
- Nodes can start operation at different times
- Clustering is triggered every T_{NO} seconds
- To handle asynchrony:
  - Every node announces its state (cluster head) with every routing update
  - A new node starts the clustering process when it starts its operation
  - When T_{NO} expires at a cluster head, it sends a routing update to trigger its neighboring cluster heads and cluster members to start the clustering process

The iHEED system



Evaluation

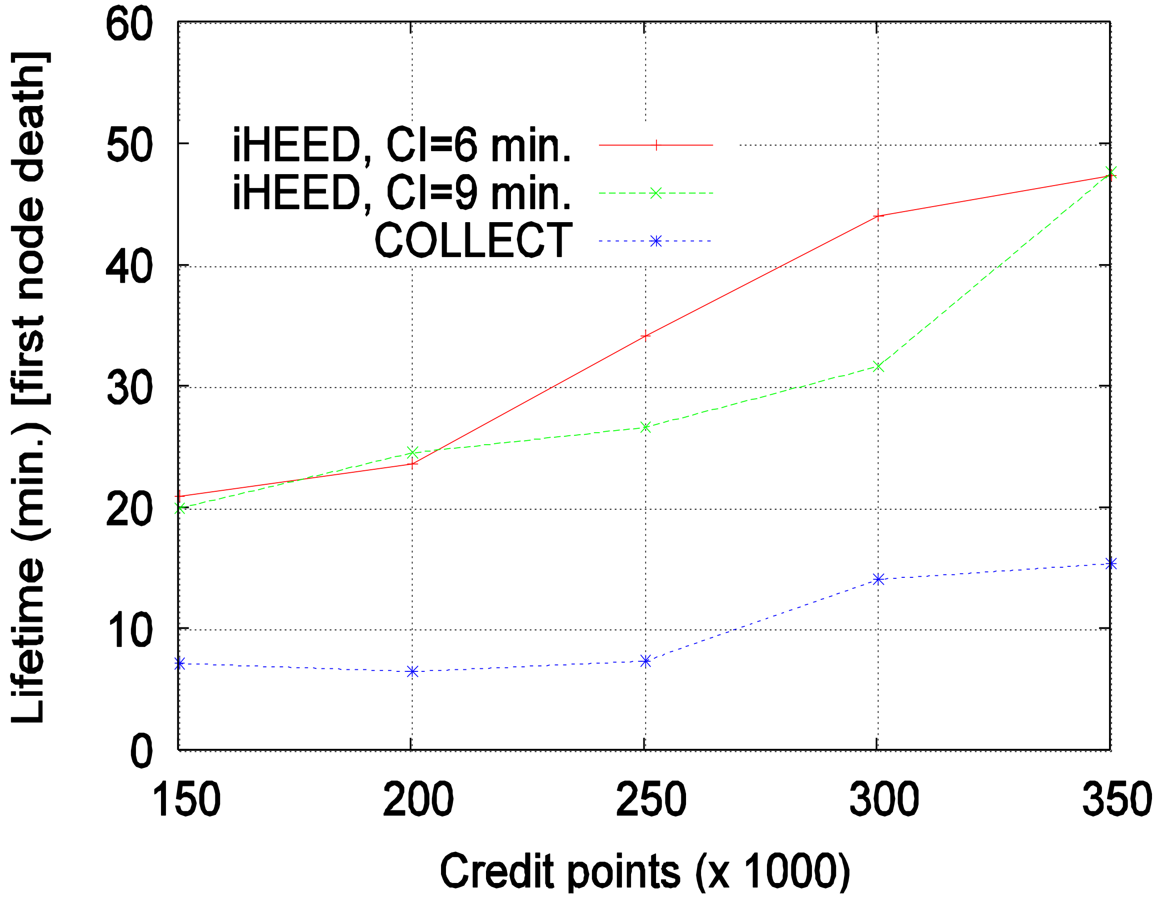
- Experimental setup:
  - 6 Mica2 + 4 Mica2Dot sensors + base station
  - Distributed in a research lab



Experimental setup

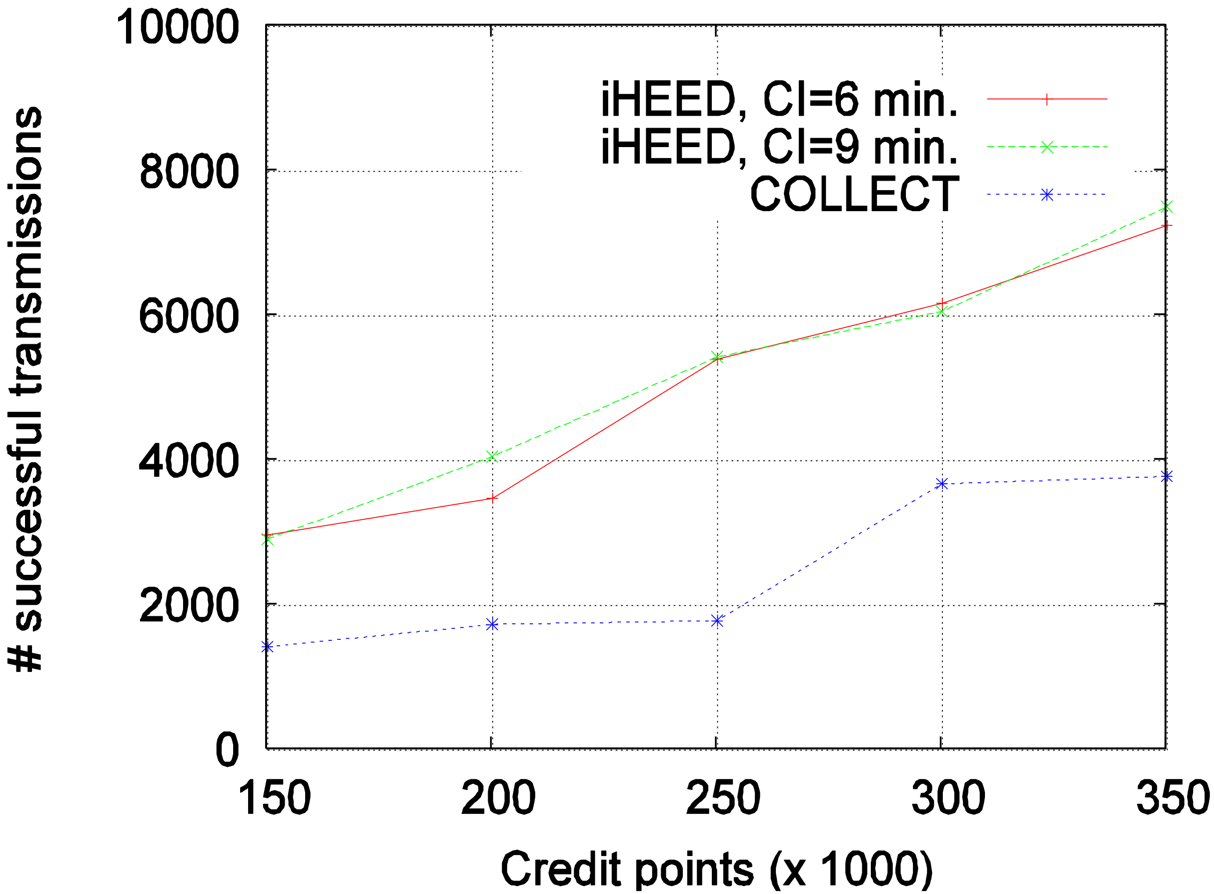
- Packet size: 36 bytes
- Routing update: 1packet every 10 seconds
- Data rate: 1 packet every 2 seconds
- E_{max} = 150,000 – 350,000 points
- Intra-cluster trans. cost = 230 points/packet
- Inter-cluster trans. cost = 291 points/packet
- Re-cluster the network every 6 (or 9) minutes

Evaluation – Network lifetime



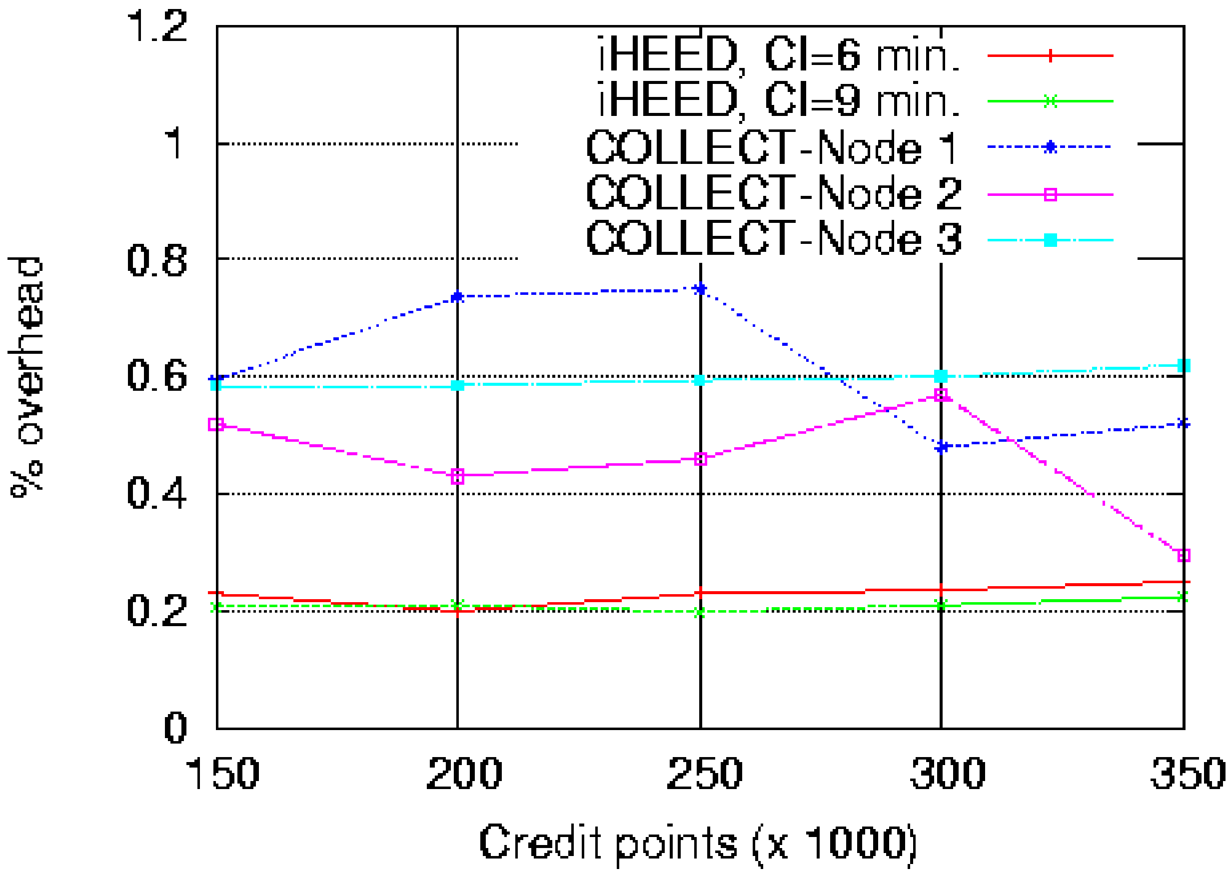
Network lifetime is prolonged by a factor of 2-4

Evaluation -- #successful transmissions



successful transmissions is almost doubled

Evaluation -- overhead



Overhead of iHEED is less than that of COLLECT

Conclusion

- Integrating clustering with data aggregation has important advantages:
  - Prolongs the network lifetime
  - Reduces channel contention
- The overhead incurred with clustering is small, compared to that of forwarding
- Integration with node duty cycle is essential for more energy conservation