Energy-Efficient Clustering Method for Data Gathering in Sensor Networks

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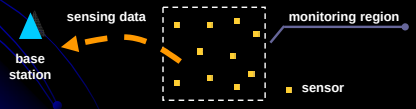
Outline

- Introduction
- Objective
- Our proposal
- Simulation
- Conclusion & future work

Sensor network

- Set up sensor nodes to monitor a region
  - Operation on a limited battery
  - Difficulty to recharge the battery
  - Transmission over wireless channel
  - Dynamical deployment and behavior
  - Location awareness (GPS, etc.)
- Gather sensor data and send to a base station (BS)



Objective

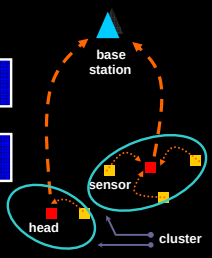
~ How to prolong lifetime of sensor networks ? ~

1. Cluster-based data gathering

• 2-hop transmission

1. Cluster members send sensor data to their cluster-heads

2. Cluster-heads send the collected sensor data to BS

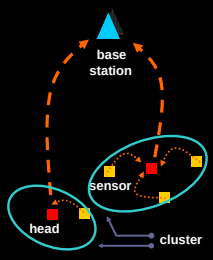


Objective

~ How to prolong lifetime of sensor networks ? ~

1. Cluster-based data gathering

- Limit communication range
  - Reduce transmission cost
  - Reduce collisions
- Local aggregation of sensor data
  - Reduce the transmission data size



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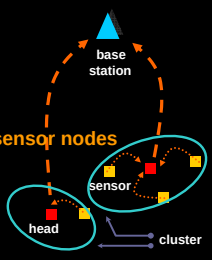
2. Equalize the residual energy of sensor nodes

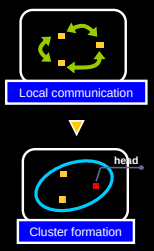
- **Rotation of cluster-heads**
  - More sensor nodes live longer period
  - Cluster-heads consume much energy
    → performed by sensor nodes with larger residual energy



Goal

To propose clustering method

- Demands
  - Completely distributed
  - Well-distributed cluster-heads
  - Energy-efficient
  - Adaptation to changes of sensor networks
- Our approach
  - Clustering through local communication among neighboring sensor nodes



Reference (ANTCLUST)

- Clustering method hinted by behavior of ants
- Chemical recognition system of ants
  - Ants spread chemical substance on their cuticles (differs by individuals, species, and environments)
  - When two ants meet, they recognize whether they are nestmates by exchanging and comparing their chemical substances
  - Chemical substance is updated at each meeting

N.Labroche, N.Monmarché, and G.Venturini , "A new clustering algorithm based on the chemical recognition of ants," in *Proceedings of the 15th European Conference on Artificial Intelligence*, pp345-349, July 2002.

Reference (ANTCLUST)

- ANTCLUST parameters
  - Ant : Object
  - Chemical : Information about object
  - Nest : Cluster
- Meeting
  - Two randomly chosen objects compare the similarity with threshold *Template*
    - Similar & different clusters ➞ move to the same cluster
    - Not similar & same cluster ➞ move to a different cluster
    - Repeat above meetings

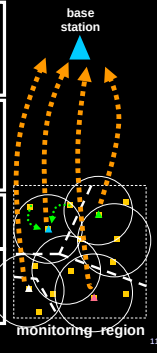
Our proposal

- Apply ANTCLUST to sensor networks
  - Ant : Sensor node
  - Similarity : Nearness to cluster-head
  - Chemical : Identifier, residual energy, location of cluster-head
  - Meeting : Information exchange by broadcasting
- Differences from ANTCLUST
  - Introduce a mechanism of cluster-head candidacy
  - Meeting by broadcasting
    - All sensor nodes within limited range receive broadcast and update parameters
    - Limited number of meetings in terms of energy

Overview of our proposal

~ "round" = one cycle of data gathering ~

1. Cluster-head Candidacy Phase
   - Sensor nodes with larger residual energy broadcast their candidacy within "R"
   - Tentative clusters are formed
2. Cluster Formation Phase
   - "P_{ex}" of sensor nodes broadcast cluster information within "r" and meet each other
   - Selection of a cluster-head
3. Registration Phase
   - Registration of members to their cluster-heads
4. Data Gathering Phase
   - Cluster members send the data to heads
   - Cluster-heads send aggregated data to BS



Information for broadcast

- Node *i* maintains the following information
  - Information about itself
    - i : identifier
    - e_i : residual energy of itself
    - P_i : probability of candidacy for a cluster-head
    - $Template_i$: threshold of similarity
  - Information about its cluster
    - $head_i$: identifier of its cluster-head
    - E_i : residual energy of its cluster-head
    - C_i : location of its cluster-head
    - M_i : estimator of the number of its cluster members
- Broadcast above information except $Template_i$, P_i

Procedure on receiving broadcasts

Suppose sensor node i receives the broadcast message of node j

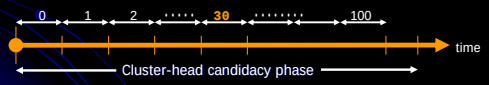
- Update probability of candidacy P_i
  - $$P_i = \begin{cases} \min(1, P_i + p), & \text{if } e_i > e_j \\ P_i, & \text{if } e_i = e_j \\ \max(0, P_i - p), & \text{if } e_i < e_j \end{cases}$$
- Update threshold $Template_i$
  - $$Template_i = \frac{\overline{d(i,\cdot)} + \max(d(i,\cdot))}{2}$$
  - $d(i, \cdot)$ is the distance to all known cluster-heads

Cluster-head candidacy phase

~ candidate ~

- At the beginning of each round
  - All sensor nodes regard themselves as cluster-heads
- Cluster–head candidacy phase has T time units duration
  - Sensor node i announces its candidacy at $T \times (1-P_i)$

e.g. If $T = 100$ and $P_i = 0.7$, then sensor node i announces its candidacy in unit 30



- Cluster-head decreases probability P

Cluster-head candidacy phase

~ receiver ~

Sensor nodes which receive candidacy message compare the distance d to a new cluster-head with threshold $Template$

- $d \leq Template$
  - *If* (the node is not a cluster-head and belongs to no cluster)
    → joins the new cluster and resigns its own candidacy
  - *Else*
    → conducts the same procedure as in the next cluster formation phase
- $d > Template$
  - does nothing

Cluster formation phase

- P_{ex} of sensor nodes which are not a cluster-head broadcast cluster information
- Sensor nodes which receive cluster information compare distance d to a new cluster-head with threshold $Template$
- *If* ($d \leq Template$)
  → choose a better cluster with larger $\frac{E}{M \cdot d^2}$
  - closer cluster-head (smaller d)
  - cluster-head with larger residual energy (larger E)
  - cluster-head with less cluster members (smaller M)

Simulation setup

- Criteria
  - Number of alive sensor nodes at the start of the round
  - Total number of sensor data received at BS
- Sensor network
  - Randomly deployed 100 nodes in a 100x100 m²
  - BS was at (50, 175)
  - Initial energy 0.5J
- Energy consumption model (k bit, d m)

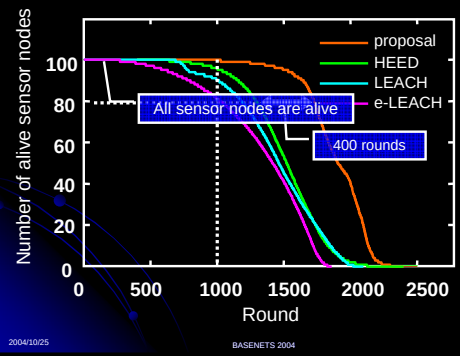
$$E_{transmit} = \begin{cases} k \cdot (E_{elec} + \varepsilon_{fs} \cdot d^2) & \text{if } d < d_{threshold} \\ k \cdot (E_{elec} + \varepsilon_{mp} \cdot d^4) & \text{if } d \geq d_{threshold} \end{cases}$$

$$E_{receive} = k \cdot E_{elec}$$

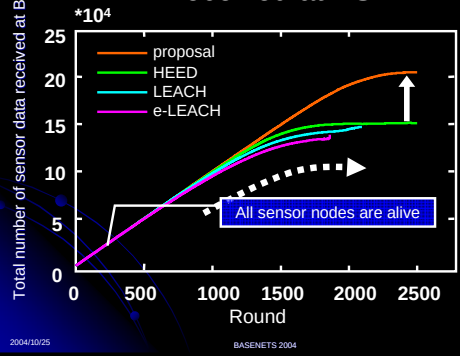
Simulation setup

- Comparative example
  - LEACH
  - e-LEACH: distributed-version of LEACH-C
  - HEED
- Parameter settings for proposal
  - Range "R" for candidacy : 40m
  - Range "r" for exchange of cluster information : 20m
  - Percentage "P_{ex}" for exchange of cluster information: 10%

Number of alive sensor nodes



Total number of sensor data received at BS



Conclusion & future work

- Conclusion
  - We proposed a clustering method for sensor networks based on ANTCLUST
  - Simulation experiments showed that in our method more sensor nodes stayed alive for a longer period than in other clustering approaches
- Future work
  - Autonomous adjustment of parameters by sensor nodes
  - Multi-hop transmission among cluster-heads

Thank you !