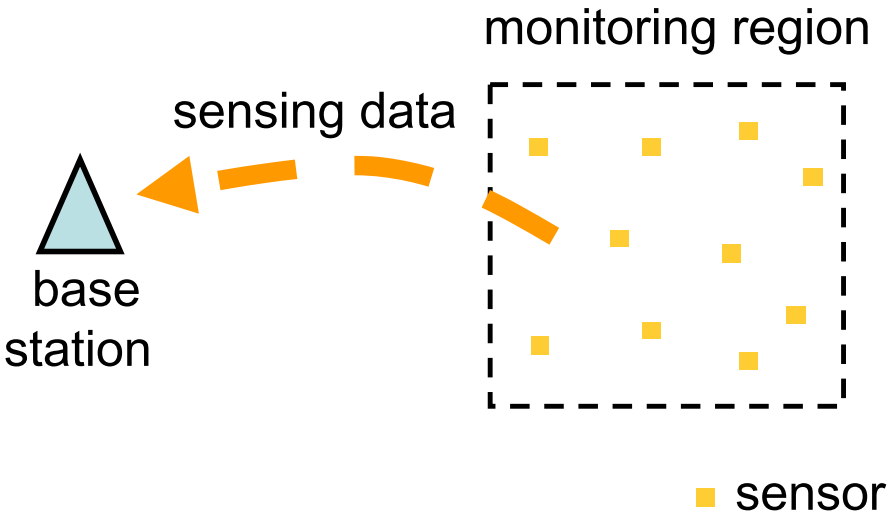
Distributed Clustering Method for Energy-Efficient Data Gathering in Sensor Networks

Junpei Kamimura, Naoki Wakamiya, Masayuki Murata
Graduate School of Information Science and Technology, Osaka University

1. Sensor Network

Network :

- Hundreds or thousands of sensor nodes are deployed to a region to monitor
- Sensor information is gathered to one base station



Sensors :

- Operate on a limited battery
- Difficult to recharge a battery
- Wireless communications
- Dynamically deployed, move, and halt
- Location aware (GPS, etc.)

Example Applications :

- Observation of severe environments (volcano, deep sea, etc.)
- Field surveillance for security
- Ecological research on wildlife

2. Objectives

Approach :

How to prolong lifetime of sensor networks ?

1. Limit communication range

Transmission cost is proportional to bit-size, *n*-th power of distance

▼

Cluster-based data gathering

-- Cluster-head gathers sensor data in its cluster

-- Cluster-head sends the collected data to a base station

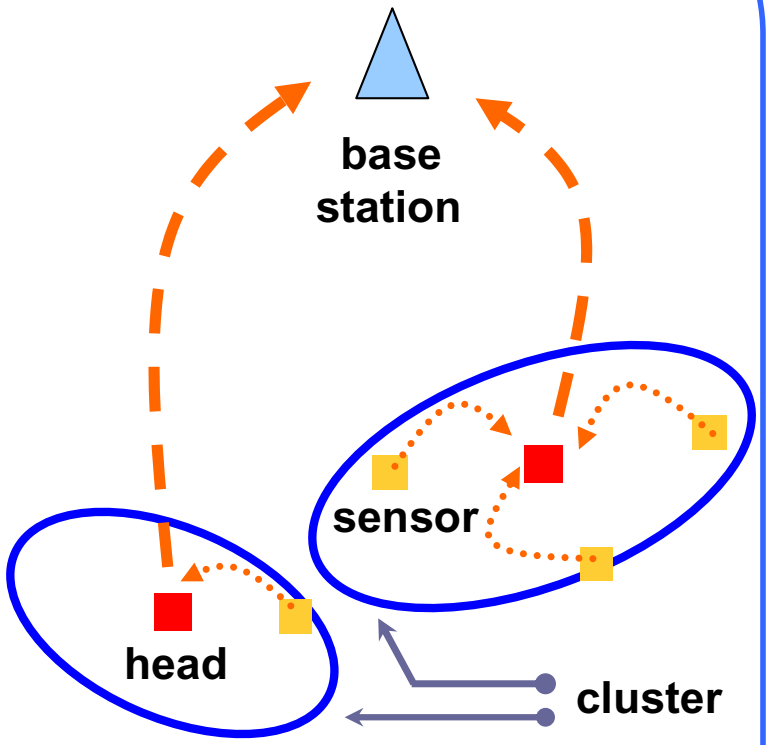
2. Equalize the residual energy of sensor nodes

Cluster-heads consume much energy

▼

Rotation of a cluster-head

-- Sensor nodes with large residual energy become cluster-heads



3. Cluster-based Data Gathering

Round :

1. Cluster-head candidacy
-- a part of sensor nodes broadcast a candidacy message

2. Cluster formation
-- Each sensor node chooses its cluster-head

3. Registration
-- Cluster members register itself to a cluster-head

4. Data gathering
-- Cluster members send sensor data to cluster-head
-- Cluster-head send aggregated data to a base station

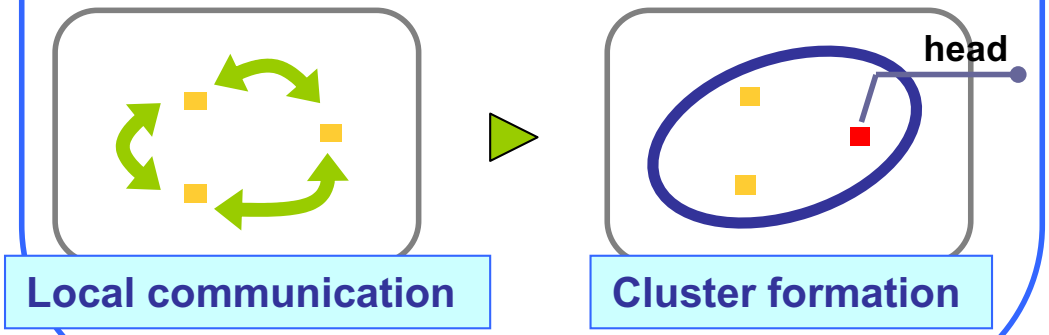
Clustering Method :

Demands :

- Completely distributed
- Well-distributed clusters
- Energy-efficient
- Adapts to changes of sensor networks
  - Scalable
  - Robust

Our Approach :

- Clustering through local communications among neighboring sensor nodes



4. Proposed Clustering Method

Reference :

- **Behavior of Ants (colonial closure)**

-- Nestmate recognition by chemical substance

-- Similar chemical substance in the same nest

- **ANTCLUST**

-- Ant = Object

-- Chemical = Information of cluster

-- Nestmate = Cluster member

-- Nest = Cluster

Randomly chosen two objects meet with each other
Clusters are created, merged, and discarded through meetings

Proposed method :

Clustering method based on ANTCLUST
two phases of cluster formation

1. Cluster-head candidacy phase

-- Sensor nodes with large residual energy announce their candidacy within range "R"

-- Tentative clusters are formed

▽

2. Cluster formation phase

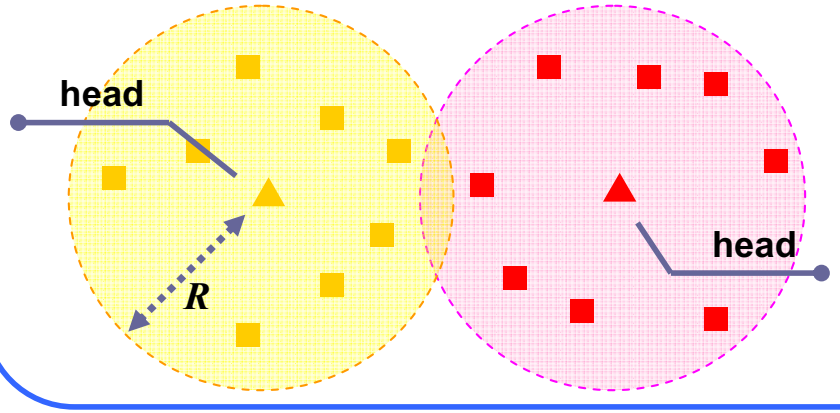
-- "P_{ex}" *of* sensor nodes broadcast their cluster information within range "r" to cause meetings

-- Belong to a better cluster

5. Data Gathering with Proposal

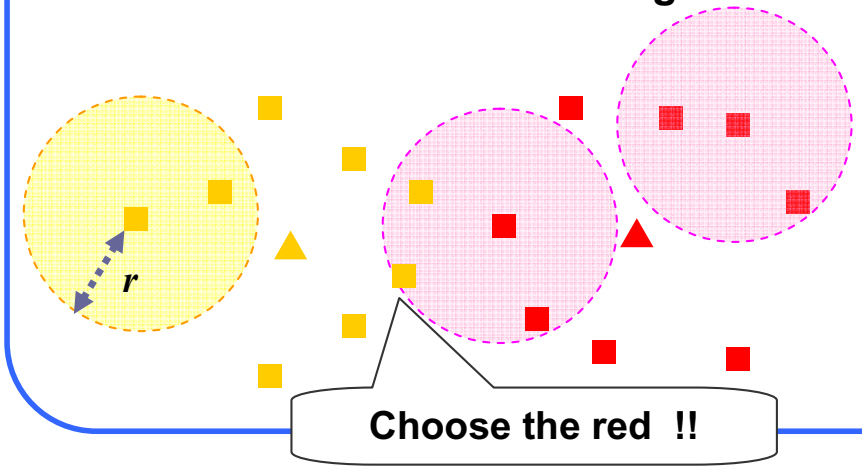
1. Cluster-head Candidacy Phase :

- Candidacy for a cluster-head



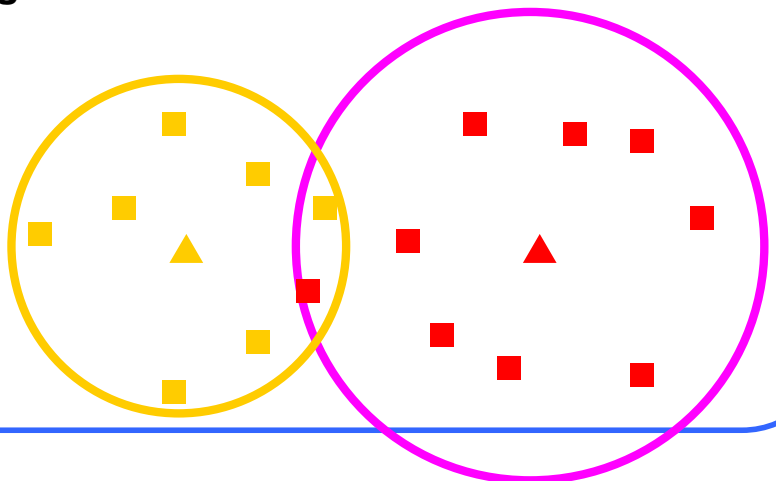
2. Cluster Formation Phase :

- Choose a better cluster through "*Meetings*"



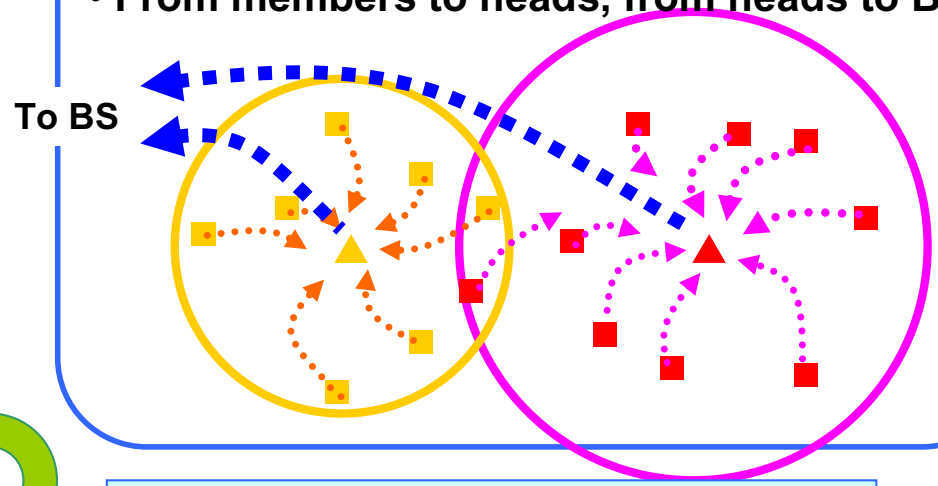
3. Registration Phase :

- Register oneself as a cluster member



4. Data Gathering Phase :

- From members to heads, from heads to BS



6. Proposed Method ~detail~

Parameters of sensor node i :

Parameters

R	: range of candidacy
r	: range of meetings
P_{ex}	: percentage of sensor nodes cause meetings

Information of sensor node

i	: identifier
c_i	: coordinates
e_i	: residual energy
P_i	: probability of candidacy
$Template_i$	: threshold variable

Information of a cluster

$head_i$	: identifier of cluster-head
E_i	: residual energy of cluster-head
C_i	: coordinates of cluster-head
M_i	: estimator of cluster member

A message contains i, e_i, $head_i$, E_i, C_i, and M_i.

At cluster-head candidacy phase and cluster formation phase, when sensor node i received a message from sensor node j, sensor node i does:

-- Update probability of candidacy P_i

$$P_i = \begin{cases} P_i + p, & \text{if } e_i > e_j \\ P_i, & \text{if } e_i = e_j \\ P_i - p, & \text{if } e_i < e_j \end{cases}$$

-- Update threshold $Template_i$

$$Template_i = \frac{\overline{d(i,\cdot)} + Max(d(i,\cdot))}{2}$$

$d(i, \cdot)$ is the distance to a newly known cluster-head

7. Cluster-head Candidacy Phase ~detail~

Candidacy for cluster-head :

Sensor nodes with larger residual energy become a cluster-head

- Cluster–head candidacy phase has T time unit duration
- Sensor node i announce its candidacy at $T(1-P_i)$
- Cluster-head decreases P_i

Neighboring node i :

Compare distance d to a new cluster-head with threshold $Template_i$

- $d <= Template_i$
  - -- *If* (sensor node i is not a cluster-head and belongs to no cluster)
    - ▶ belongs to the new cluster
  - -- *Else*
    - ▶ conducts the same procedure as in the next cluster formation phase
- $d > Template_i$
  - -- does nothing

8. Cluster Formation Phase ~detail~

Meetings :

P_{ex} of sensor nodes which are not a cluster-head broadcast cluster information

Neighboring node i :

- Compare distance d to a new cluster-head with threshold $Template_i$

$If\ (d <= Template_i)$ ▶ choose a better cluster

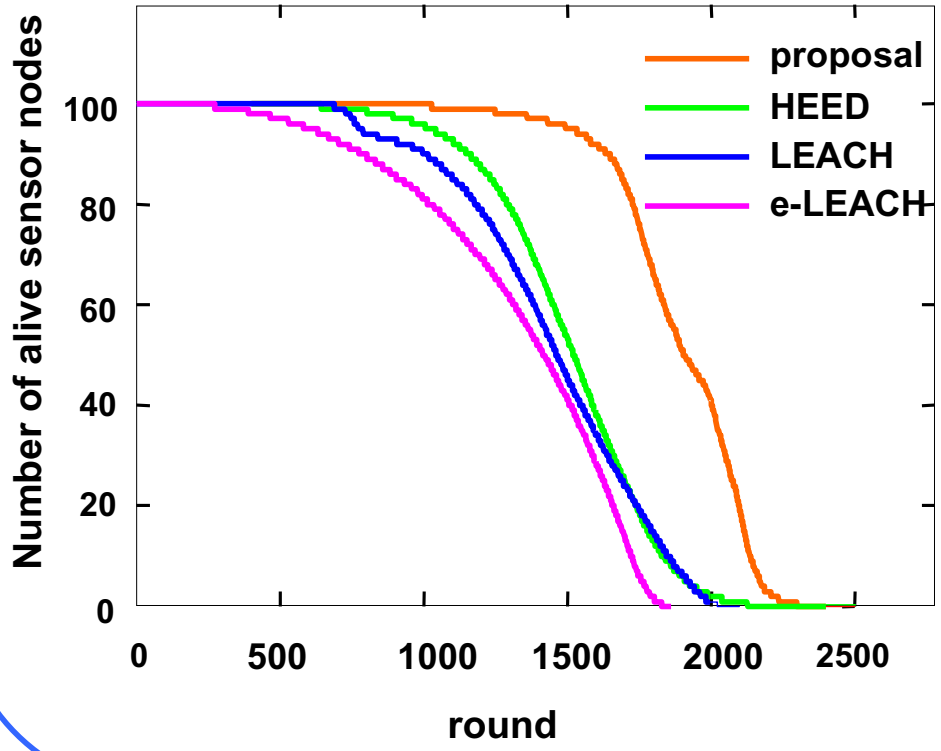
- closer cluster-head (smaller d)
- cluster-head with larger residual energy (larger E)
- cluster-head with less cluster members (smaller M)

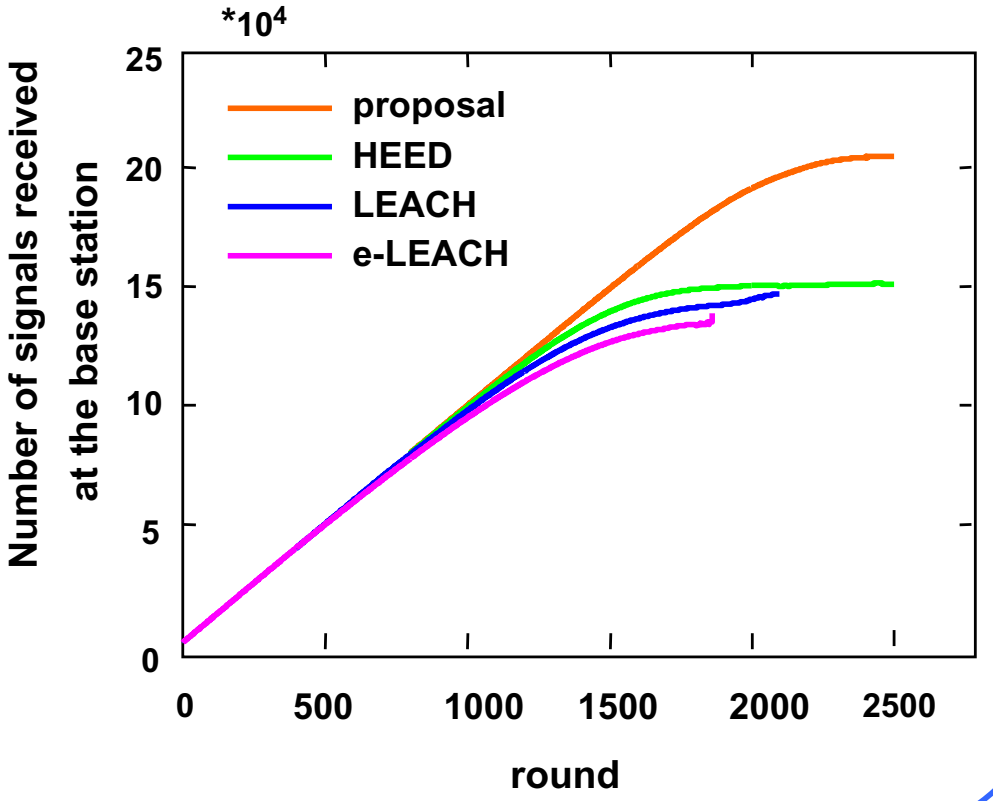
Compare the value $\frac{E}{M \cdot d^2}$ of current cluster with newly known cluster

Then, belong to the cluster with large value

9. Simulation Experiments

- Comparison with HEED, LEACH, and e-LEACH
  - For each of methods, parameters were set to derive the best performance
- Setup: 100x100 area, 100 nodes, and initial energy 0.5J





10. Future Work

- Consider the case where data aggregation is impossible
- Introduce multi-hop transmission among cluster-heads
  - To adapt to large scale sensor networks

Contact us :

Junpei Kamimura, Naoki Wakamiya, Masayuki Murata
Graduate School of Information Science and Technology, Osaka University
1-5 Yamadaoka, Suita, Osaka 565-0871, Japan
E-mail: {kamimura, wakamiya, murata} @ist.osaka-u.ac.jp