Error-tolerant coverage control based on bio-inspired attractor selection model for wireless sensor networks

Takuya Iwai, Naoki Wakamiya, Masayuki Murata
Osaka University, Japan

Coverage problem in wireless sensor networks

- Wireless sensor networks (WSNs)
  - Wide range of applications
    - e.g., surveillance, environment monitoring, and health care
  - Many sensor nodes (thousands ~ tens of thousands)
  - Limited battery
- Coverage problem
  - Guaranteeing the target region are monitored
  - Prolonging the lifetime of WSNs

Existing coverage control proposals

- Estimation of a degree of coverage inside a sensor node’s sensing area with a geometric algorithm
- Selection of sensor node’s state, i.e. active or sleep, based on the degree of coverage inside its sensing area
- Unrealistic assumption
  - Accurate location
  - Circular sensing area
  - High overhead
  - Exchanging information required for the algorithm
- Decrease of performance suffering from error (e.g. short coverage and redundant active nodes)
- Reduced life time of WSNs

Research objectives

- Error-tolerant and low-overhead coverage control method
  - Nonuse of information of error-prone neighboring nodes (e.g. location and shape of sensing area)
  - A small number of message transmissions
  - Application of creature’s autonomous state selection mechanism to sensor node’s autonomous state selection
  - Target application
    - Periodic monitoring
  - E.coli’s adaptive behavior to dynamically changing environment

Attractor selection model for coverage control

- E.coli’s adaptive behavior to dynamically changing environment
  \[
  \frac{d}{dt} x = f(x) + \eta
  \]
  - Potential function
    - Goodness of the state (activity)
    - Gaussian noise
  - Coming close to appropriate state (increase of \( x \))
  - \( x \): State
  - \( f(x) \): Potential function
  - \( \eta \): Goodness of the state (activity)
  - \( \eta \): Gaussian noise

Exchanging information
- Circular sensing area
- Accurate location
- Periodic monitoring
- Error-tolerant and low-overhead coverage control method

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Coverage configuration protocol (CCP)

- For 1-Coverage, all intersection points between any sensor nodes’ sensing area are covered by at least 1 sensor node.

Error-tolerant and low-overhead coverage control method

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E.coli’s adaptive behavior to dynamically changing environment
### Activity for coverage control

- Activity $\alpha$ is defined as goodness of coverage condition.

<table>
<thead>
<tr>
<th>High activity</th>
<th>Low activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good coverage</td>
<td>Short coverage</td>
</tr>
</tbody>
</table>

- On the timing of data gathering, sink node collects sensing data periodically.
- Sink node derives and disseminates the activity information (coverage degree).
- Sensor node evaluates the attractor selection model and determines its state.

**Activity $\alpha$** (coverage degree)

- For fine-grained control, a sink node derives activity per sub-area and sensor nodes use activity of a sub-area where they consider to be located.
  - A change of node state directly influences “Area activity” more than “Global activity”.
  - Nodes with localization error may use an area activity of wrong sub-area.

### Overview of our proposal (1/4)

1. On the timing of data gathering, sink node collects sensing data periodically.
2. Sink node derives and disseminates the activity information (coverage degree).
3. Sensor node evaluates the activity and determines its state.

- Sensing data
- Information for sink node to estimate degree of coverage

### Overview of our proposal (2/4)

1. On the timing of data gathering, sink node collects sensing data periodically.
2. Sink node derives and disseminates the activity information (coverage degree).
3. Sensor node evaluates the attractor selection model and determines its state.

### Overview of our proposal (3/4)

1. On the timing of data gathering, sink node collects sensing data periodically.
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### Overview of our proposal (4/4)

1. On the timing of data gathering, sink node collects sensing data periodically.
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3. Sensor node evaluates the attractor selection model and determines its state.

### Simulation evaluation

- Examination of our proposal's localization error tolerance and low overhead through comparison with CCP
- Location error uniformly distributed between $-\delta [\text{m}]$ and $+\delta [\text{m}]$
- 10,000 nodes randomly deployed in $500 \times 500$ [$\text{m}^2$]
- Global activity and area activity: 400 sub-areas of $25 \times 25$ [$\text{m}^2$]
- Gathering sensing data every 10 [$\text{s}$]

<table>
<thead>
<tr>
<th>Sensing area (radius of circle)</th>
<th>Communication range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our proposal 10 [m]</td>
<td>large enough to keep connectivity</td>
</tr>
<tr>
<td>CCP 10 [m]</td>
<td>20 [m]</td>
</tr>
</tbody>
</table>
Simulation result (sensing ratio)

- Sensing ratio
  - The degree of coverage over the whole region

![Graph showing sensing ratio comparison between proposed global activity, proposed area activity, and CCP.]

The global activity-based control keeps its coverage against different degrees of localization error.

Simulation result (contribution ratio)

- Contribution ratio
  - The average area that an active node contributes to coverage

![Graph showing contribution ratio comparison between proposed global activity, proposed area activity, and CCP.]

When localization error is large, our proposal is more efficient than CCP.

Simulation result (overhead)

- Overhead
  - The total number of transmitted messages

![Graph showing overhead comparison between proposed global activity, proposed area activity, and CCP.]

Our proposal’s overhead is less than CCP.

Conclusion and future work

- Conclusion
  - Propose bio-inspired coverage control method for WSNs
  - Confirm the error tolerance and low overhead

- Future work
  - Improve performance by introduction of other activity’s definition
  - Evaluate energy consumption

Thank you for your attention.