Error-tolerant and energy-efficient coverage control based on attractor selection model for wireless sensor networks

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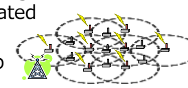
Coverage problem in WSNs

- Wireless sensor networks (WSNs)
  - Wide range of applications
    e.g.) intrusion detection, environmental monitoring and optimization of harvesting
  - Difficulty to optimally deploy sensor nodes
    → Redundant distribution of nodes
  - Limited battery
- Coverage problem
  - Guaranteeing the sufficient coverage by letting necessary nodes activated
  - Prolonging the lifetime of WSNs by letting redundant nodes sleep



Existing coverage control proposals

- Select a node's state, i.e. active or sleep, based on the degree of coverage inside its sensing area
- Estimate a degree of coverage inside a node's sensing area with a geometric algorithm
- Unrealistic assumption
  - Accurate location
  - Circular sensing area

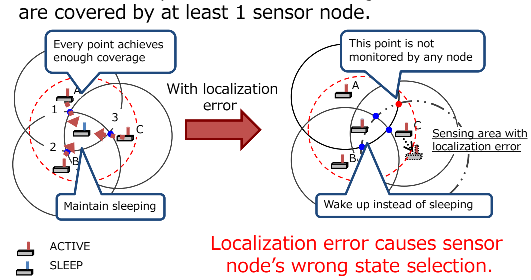
  ⇒ Error causes decrease of performance (e.g. short coverage, redundant active nodes)
- High overhead
  - Exchanging information required for the algorithm

  ⇒ Reduced life time of WSNs

[2] X. Wang, G. Xing, Y. Zhang, C. Lu, R. Pless, and C. Gill, "Integrated coverage and connectivity configuration in wireless sensor networks," in Proceedings of ACM SenSys, pp. 33–72, August 2003.

CCP (Coverage Configuration Protocol)[2]

- All intersection points between sensing areas are covered by at least 1 sensor node.



Localization error causes sensor node's wrong state selection.

Research objectives and ideas

- Error-tolerant and energy-efficient state selection
  - Low dependency of neighboring node's location and shape of sensing area
  - Small number of message transmissions
- Bacteria's adaptive nutrient synthesis
  - Selective synthesize of nutrient to survive
  - Without communication with other bacteria
    → Using activity and noise

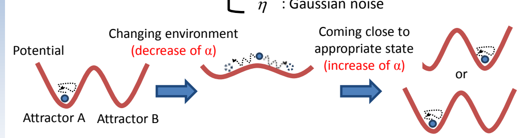
E.coli (Escherichia coli)

Attractor selection model for coverage problem

- *E.coli*'s adaptive behavior to dynamically changing nutrition condition

$$\frac{d}{dt}\vec{x} = f(\vec{x}) \times \alpha + \vec{\eta}$$

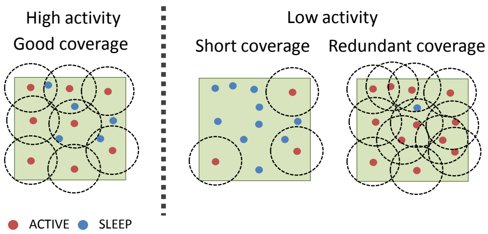
- $\vec{x}$: State
- $f(\vec{x})$: Potential function
- α : Goodness of the state (activity)
- $\vec{\eta}$: Gaussian noise



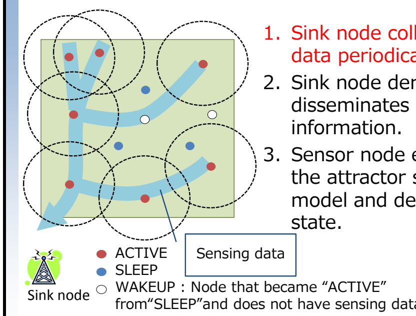
	Activity	Attractor A	Attractor B
E.coli	Growth rate	Folic acid	Glutamine
Coverage	Goodness of coverage condition	Active	Sleep

Activity's definition

- Activity α is defined as goodness of coverage condition.

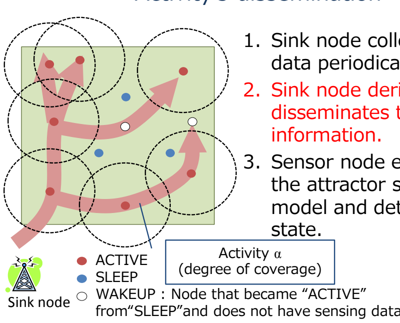


Periodic sensing data gathering



1. Sink node collects sensing data periodically.
2. Sink node derives and disseminates the activity information.
3. Sensor node evaluates the attractor selection model and determines its state.

Activity's dissemination



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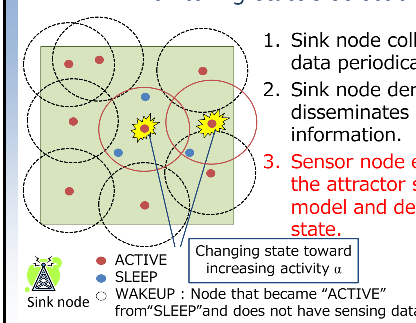
Monitoring state's selection



1. Sink node collects sensing data periodically.
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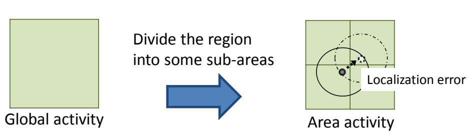
Variations of activity



- 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.

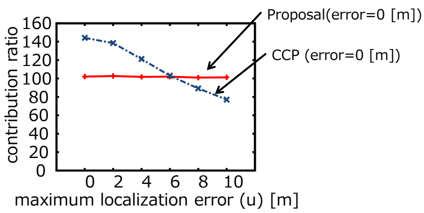
Simulation evaluation

- Examine our proposal's localization error tolerance and low overhead against CCP
- Localization error uniformly distributed between $-u$ [m] and $+u$ [m]
- Global activity

Field	500 × 500 [m^2]
Node	10,000 nodes, random destribution
Communication range	20 [m]
Sensing area (radius of circle)	10 [m]
Interval between sensing data gatherings	10 [s]

Contribution ratio

- The average area that an active node contributes to coverage

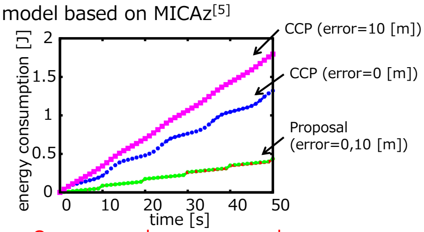


When localization error is large, our proposal is more efficient than CCP.

[5] Crossbow Technology, "MICAz Datasheet." http://www.xbow.com.

Energy consumption

- The average energy consumption per node with and without localization error
- Energy model based on MICAz[5]



Our proposal consumes only 1/4 ～ 1/3 energy of CCP.

Conclusion

- Propose bio-inspired coverage control method
  - Autonomous state selection of nodes based-on the attractor selection model
  - Low dependency of information about neighboring nodes
  - Small number of message transmissions
- Confirm the error tolerance and low energy consumption through simulation

Thank you for your attention.