Differences in Robustness of Self-Organized Control and Centralized Control in Sensor Networks Caused by Differences in Control Dependence

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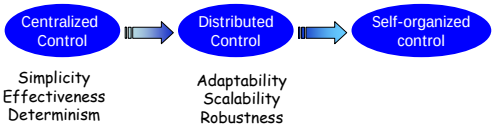
Attention to self-organization

- Paradigm shift of control process



Simplicity
Effectiveness
Determinism

Adaptability
Scalability
Robustness

- Self-organization
  - Is "emergence of system-wide adaptive structure and functionality from simple local interactions between individual entities" [Prehofer and Bettstetter, 2005]
  - Attracts considerable attention from the view point of the applicability to sensor networks

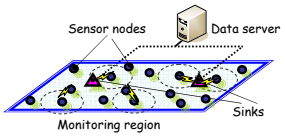
Motivations

- Robustness
  - Is "a property that allows a system to maintain its functions despite external and internal perturbations"
  - Is extremely important especially for networks in variable environment
- Good robustness of self-organized control is widely reported but:
  - This is certainly nontrivial
    - Why self-organized control is robust?
    - What factors yield robustness?
- Compare robustness of self-organized control and centralized control
  - Using sensor network scenario
  - Quantitatively demonstrate the advantage of robustness
  - Yield insight why and how self-organized control achieve good robustness

What is WSN

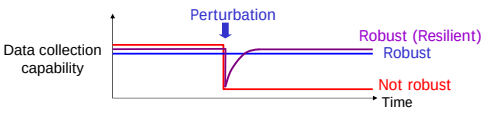
- Wireless Sensor Network (WSN)
  - Composed of a number of sensor nodes
    - Have miniature sensing devices
      - Ex., Moisture, temperature, acceleration
    - Communicate with neighboring nodes via wireless channel
    - Sense their ambient surroundings
    - Send the data to a sink
  - Collect data over a large area

- Perturbations WSN faces
  - Transmission error
  - Sensor node failures



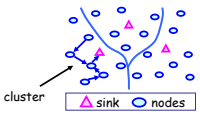
Robustness in sensor network

- Robustness
  - Property which allows a system to maintain its functionality despite perturbations
- Robustness in sensor networks
  - Perturbation: Packet loss, link disconnection, node & sink failure
  - System: Sensor network
  - Function: Data collection



Centralized control in our comparison

- Cluster-based approach
  - Sensor nodes are divided into as many clusters as sinks
  - Routing is performed in each cluster
- Control station manages network
  - Gather and integrate control information from each node
    - Positions, residual power, etc. of nodes.
  - Draw a whole picture of the network
  - Manage clusters and routes based on the picture
- Countermeasures against node failures
  - Each node periodically transmits hello message
  - A node detects failure if a node cannot receive the message from another node for a predefined time
  - Failure indication is sent to the control station



Self-organization in Nature

- Ants or Bees
  - Each agent is simple and unintelligent
  - Interacts with neighboring agents
  - Obeys the local rules it has as a species
- Their collective action creates biological order
  - Allocating tasks
  - Finding shortest path to their food

Many researchers have tried to derive advantageous properties from biological system: Bio-inspired Control

Self-organized control in our comparison

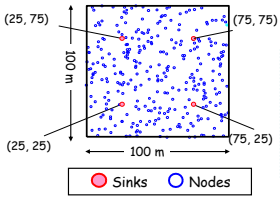
- Cluster-based approach
  - Same as the centralized control
    - Sensor nodes are divided into some clusters
    - Routing is performed in each cluster
  - Combination of two swarm intelligence of ants
    - Ant-based clustering for clustering
    - Ant colony optimization (ACO) for routing

These are mediated by "pheromone"

  - Fault management
    - Failure detection is same as that of centralized control
    - There is no explicit failure indication

Simulation settings

- 100x100m² monitoring region
- 300 nodes
- 4 sinks
- 10m transmission range
- Data packets is transmitted every 10 seconds to a sink
- Using network simulator ns-2



Metric of robustness

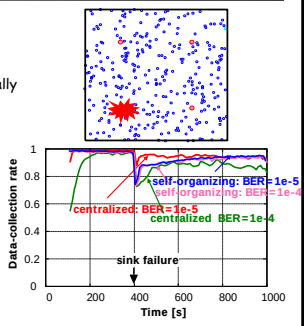
Data-collection rate: r/s

where

- r : Number of packets received by sinks
- s : Number of packets transmitted

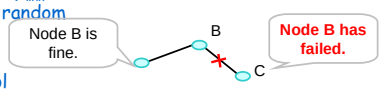
Recovery from sink failure

- If a sink fails…
  - Self-organized control
    - Adjacent node detects sink failure
    - Form of clusters change gradually
  - Centralized control
    - Control station detects failure immediately
    - Clusters' reconstruction starts
- Small BER:
  - Concentrated control recovers performance quickly
- Large BER:
  - Performance recovery of concentrated control becomes slow

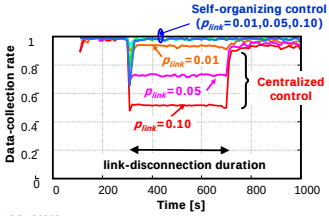


Influence of link disconnection

- Link of the rate of p_{link} was disconnected for 100 seconds to 500 seconds at random



- Centralized control
  - Control station performs control based on the erroneous information
- Self-organized control
  - Error of each node does not influence the whole network



Dependence on control information

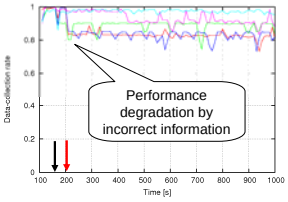
- Dependence
  - Term used by Fault Management
  - Error of a certain object causes the error of other objects.
- Control information
  - Information exchanged between entities for cooperation
- Problem about control information
  - Control information does not arrive at control station
  - Contents of the control information itself are erroneous

Dependence is major factor of the difference in the robustness between self-organized and centralized control

False-recovery information

- 160 sec: A node near the sink (25, 25) fails
- 200 sec: Injection of incorrect information
  "Node has recovered !"

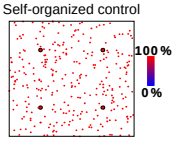
- Centralized control
  - Performance deteriorates for the control based on incorrect information
- Self-organized control
  - No performance degradation resulting from incorrect information



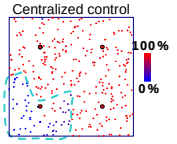
Influence of incorrect information

- Errors are contained in the control information obtained from each node
  - Reliability of each node is not so high
  - Cannot recognize change of network composition precisely
- Self-organized control
  - The control information from a node influences only in the neighborhood
- Centralized control
  - Control station understands the state of the whole network based on the information from each node

Self-organized control



Centralized control



Conclusion and future work

- Characteristic of self-organized control and centralized control was compared
  - Evaluated by simulations for sensor network system
- Robustness of self-organized control
  - Control information is exchanged locally
  - Influence of erroneous information is small
- Fragility of centralized control
  - Control station integrates individual control information and understands the state of the whole network
  - Erroneous information affects the whole system
- Future work
  - Quantification of dependency strength
  - Generalization of results

Thank you !