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
  - Centralized Control
  - Distributed Control
  - Self-organized control

- 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 viewpoint of the applicability to sensor networks

Motivations

- Robustness
  - "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 achieves 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

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
  - 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
  - Locations, 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 systems.

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

These are mediated by “pheromone.”

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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: \( r/s \)
  - \( r \): 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

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!