Collaborative Processing in Sensor Networks

Lecture 6 - Self-deployment

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Research Focus - Recap

- Develop energy-efficient collaborative processing algorithms with fault tolerance in sensor networks
  - Where to perform collaboration?
    - Computing paradigms
  - Who should participate in the collaboration?
    - Reactive clustering protocols
    - Sensor selection protocols
  - How to conduct collaboration?
    - In-network processing
    - Self deployment $\leftrightarrow$ Coverage
Self-Deployable Sensor Networks: Two Inter-related Issues

- Optimal placement design
  - What is optimal? (application oriented)
- Convergence from initial state to optimal state by sensor movement
Challenges

• Hurdles
  – Centralized deployment
  – Homogenous sensor platforms

• Solutions
  – Self-deployable sensor network
  – Heterogeneous sensor platforms
  – Mission-oriented

Biologically-inspired approaches
Biological Background

The cone mosaic of fish retina


Biological Background (cont)

Human retina mosaic
- Irregularity reduces visual acuity for high-frequency signals
- Introduce random noise

The mosaic array of most vertebrates is regular

Color filter arrays used in digital camera
The Optimal Placement Algorithm

• What types of different sensors to deploy given a certain task?
• How many sensors of each type to deploy?
• How to spatially arrange the sensors to achieve maximum performance with minimum sensor node?
Two-layer Optimal Placement
Optimality Evaluation
Self-deployment Algorithm

• Random movement
  – At each position, the sensor randomly choose one direction to go.

• Movement based on centralized control
  – The sensor needs to communicate with the base station. The deployment algorithm is carried out by the base station.
  – The sensor movement is guided by the base station.

• Swarm intelligence-based movement without communication

• SI with communication
Swarm Intelligence-based Movement

• What is SI-based algorithm?
  – Stimulated from social insects society, like ants, bees, etc.
  – Simple rules carried by individual can lead to complex behavior of the whole system.
  – TSP, network routing, optimization, etc.

• SI-based movement
  – Each sensor carries a rule which guides the movement and leads to an optimal configuration of the sensor network.
  – What’s the rule set?
Rules Carried by Each Sensor

- The movement direction is based on the current location and sensor type (where I am and where to go?)

```plaintext
Rules carried by type 1 sensor:
While x mod 2 != 0 and y mod 2 != 0 do
  if (x+y) mod 2 != 0
    if x mod 2 == 1 then
      random walk N,S;
    else
      random walk W,E;
    end
  else
    random walk NW,NE,SW,SE;
  end
end
```
Stopping Criteria

• The optimal placement confines the sensor site of different sensor platforms.

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$x \mod 2 = 0$ AND $y \mod 2 = 0$</td>
</tr>
<tr>
<td>2</td>
<td>$x+y \mod 2 = 1$</td>
</tr>
<tr>
<td>3</td>
<td>$x \mod 2 = 1$ AND $y \mod 2 = 1$</td>
</tr>
<tr>
<td>4</td>
<td>$x \mod 2 = 0$ AND $y \mod 2 = 1$</td>
</tr>
<tr>
<td>5</td>
<td>$x \mod 2 = 0$ AND $x+y \mod 4 = 0$</td>
</tr>
<tr>
<td>6</td>
<td>$x \mod 2 = 1$ AND $x+y \mod 4 = 1$</td>
</tr>
<tr>
<td>7</td>
<td>$x \mod 2 = 1$ AND $x+y \mod 4 = 2$</td>
</tr>
<tr>
<td>8</td>
<td>$x \mod 2 = 0$ AND $x+y \mod 4 = 2$</td>
</tr>
</tbody>
</table>

3 sensor types

7 sensor types
Performance Metric

- Network coverage
  - Probabilistic sensing model:
  - Probabilistic coverage:

  The coverage of grid point $n$

  $\text{cover}_n = \sum_{t=1}^{T} e^{-\alpha_t d(s_t, g_n)} u(C_t - d_t) / T$

- Convergence time
  - The number of epochs of the last positioned sensor.

- Energy consumption
  - Mechanical movement:
  - Communication:

  $E_{move} = d e_{move}$
  $E_{rcv} = e_{elec} B$
  $E_{tran} = e_{elec} B + e_{amp} d^2 B$
Simulation and Evaluation

• Simulation environment
  – Sensing field: 50m×50m -> 8×8 grid points
  – 64 sensors of 5 different types: r=1/4:1/4:1/4:1/8:1/8
  – Sensing distance: 10m
  – Initial energy:
  – Unit consumption in movement:
  – Electric circuitry:
  – Transmitter amplifier:
  – Location of base station: (0,0)
Simulation and Evaluation...

Network coverage
Simulation and Evaluation

Energy consumption

![Graph showing energy consumption vs. different ratios](image)
Discussion

• Optimal placement provides reliable coverage.
• Comparison of movement strategies.
  – Random movement consumes more energy, no communication is needed.
  – Centralized control converges the fast at the cost of full communication, where the energy consumption in communication is dominant.
  – SI-based method provides a good tradeoff in terms of convergence time and energy consumption.
Experiments and Demos
Localization

- Existing methods
  - GPS
  - Wireless triangulation
  - Laser ranger
  - Visual landmark
    - Natural
    - Structured markers

- Localizing the MSP
  - The pose estimate consists of x, y, z coordinates
    - x: the lateral translation wrt the marker
    - y: the vertical translation wrt the marker (not used)
    - z: the distance from the plane of the marker
  - Assume marker location is known *a-priori.*
The ARToolKit for Localization

- Open-source software, widely used to create augment reality (AR) applications
- The pose estimation component of the ARToolKit facilitates localization
Localization Algorithm

• Step 1: Make a 360 degree turn. If marker detected, go to step 3; otherwise, go to step 2.
• Step 2: Move 1 meter forward. If an obstacle is encountered, turn right. If marker detected, go to step 3; otherwise go to step 1.
• Step 3: If farther than 1.5 meters from the marker, move towards marker until within 1.5 meters. Adjust motor speed to keep the marker in the field of view.
• Step 4: The current pose estimate is used to calculate the position in the map.
Localization Demo - 1
Localization Demo - 2
Deployment

• Assumption: Target positions are known
• Centralized deployment
  – Client/server model
  – Server makes all the decisions
  – Optimized placement and path planning
  – Slower performance
• Distributed self-deployment
  – Peer-to-peer model
  – Client makes all decisions
  – Sub-optimal placement and path planning
  – Faster performance
Centralized Deployment Demo
Distributed Deployment Demo
Reference

