Report Documentation Page

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE  
   JUN 2004

2. REPORT TYPE

3. DATES COVERED

4. TITLE AND SUBTITLE
   Multi-Agent Simulations for Assessing Massive Sensor Deployment (Briefing Charts)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
   Naval Postgraduate School, 833 Dyer Road, Monterey, CA, 93943

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
   Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
   The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:
   a. REPORT
      unclassified
   b. ABSTRACT
      unclassified
   c. THIS PAGE
      unclassified

17. LIMITATION OF ABSTRACT

18. NUMBER OF PAGES
   22

19a. NAME OF RESPONSIBLE PERSON

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
Multi-Agent Simulations for Assessing Massive Sensor Deployment

Captain Sean Hynes, USMC
sehynes@nps.edu

Dr. Neil Rowe
nrowe@nps.edu
Outline

- Problem Space
- Sensor Coverage
- Sensor Deployment
Problem Space

Next-generation Web and network-centric warfare
Counterintelligence
Expeditionary sensor networks
Coverage, minimal exposure, and cost
Efficient deployment algorithms for autonomous sensor vehicles
Research Project

- A sensor network simulation
- Coverage and deployment issues for mobile and non-mobile sensors
- An expeditionary sensor network multi-agent simulation designed and implemented
- Novel search, coverage, and deployment algorithms implemented, tested, and compared to known methods
Coverage in Sensor Networks

We address distribution of multiple homogeneous sensors for detecting targets.
We assume a large enough number of sensors that a human operator cannot manage each.
Much literature on search in operations research.
Some literature on area coverage.
Not much literature on traversal detection.
Which Deployment = Better Coverage?

Area Coverage Deployment (More Area Covered)

Barrier Coverage Deployment (More Likely Traversal Detection)
Application Preview
Dimensions of sensor networks

- General sensor mechanism
  - Radial
  - Distance-directed
  - Line-of-sight
- Coverage type (sweep, area, traversal)
- Presence/absence of obstacles
- Mobility
- Localization
Deployment Algorithms: Constraints

- Should be efficient, de-centralized, fault-tolerant, and scaleable
- Communications
- Geographical Knowledge
- Localized Decisions
A grid for detecting traversal: calculate worst-case path

\[ S(s, p) = \frac{\lambda}{[d(s, p)]^K} \]

Probability of detection = 87%
Consider
• N – # Sensor Nodes
• A – environment area
• D – length of grid square

Consider
• N – 10
• A – 100 m²
• D – 10m

# of Configurations
\[ C = (D \times A)^N \]

\[ C = (10 \times 100)^{10} = (10)^{20} \]
Mobile Sensor Model

Sensor

Vehicle

Target

Feeler
Deployment Algorithms: Methods

- Global or centralized
  - Best-first, greedy, genetic, simulated annealing, ….
- Local or autonomous
  - Potential forces, vector field, local direction, ….
  - Coevolution of evasion and detection with neural networks
### Average barrier coverage (%) with multistage random deployment

<table>
<thead>
<tr>
<th>Number of sensors</th>
<th>2</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage %, no obstacles</td>
<td>4</td>
<td>41</td>
<td>64</td>
<td>85</td>
</tr>
<tr>
<td>Coverage %, with obstacles</td>
<td>6</td>
<td>25</td>
<td>39</td>
<td>55</td>
</tr>
</tbody>
</table>
Cost of achieving 80% coverage with multistep deployment of sensors

Cost for $Cd=5$ and $Cs=1$

Coverage = 80%

- With occlusion
- Without occlusion

Expected Cost

Number of sensors each step
Algorithm comparison, no obstacles

Algorithm Coverage Comparison

Detection Probability

Barrier - Not Occluded

Number of Sensors
Algorithm comparison, with obstacles
Some Pics

Free Detection Probability = 1-Exposure = 0.3432
Obstructed Detection Probability = 1-Exposure = 0.9949
Free Avg Detection Probability = 1-Exposure = 0.0751
Obstructed Avg Detection Probability = 1-Exposure = 0.0824
Some Pics

A

B

C

D
Some Pics