Evaluating and Improving the Area Coverage and Detectability in Large-scale Surveillance Networks

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Outline

- Introduction
- Sensing Models
- Deployment Strategies
- Evaluation and Improvement
- Coverage Algorithms
- Conclusions and Future Work

Introduction (1)

- Coverage: capability to sense phenomenon
- Connectivity:
  capability to communicate the sensed data
- Fundamental in WSN deployment
- Key parameters:
  - radio/sensing propagation characteristics (models) for specific sensors & environment;
  - deployment model: sensor placement & density (dense or sparse)

Introduction (2)

- Network optimization:
  lifetime vs. minimum # nodes vs. reliability
- Choice: 1-node / k-node coverage/connectivity
- Node scheduling:
  min # nodes to provide desired coverage
- Measure of the area of interest:
  area coverage, point coverage & barrier coverage
- Achieved, improved w/ stationary nodes,
  improved w/ mobile nodes
- Focus: coverage, not connectivity

Sensing Models (1)

- Sensing area around WSN node
- Idealized (Boolean / binary):

  disc → sensing radius, R_S

  - In literature, the most used one.
- General model: received energy = f(emitted event energy, environment, sensor physics)

$$S(s,p)=\begin{cases}\dfrac{\alpha}{d(s,p)^{\beta}}, A\leqslant d(s,p)\leqslant B\\ 0, otherwise\end{cases}$$

- Radio, acoustic & seismic signals

Sensing Models (2)

- Probabilistic sensing (detection) models

- Elfes': exp in uncertainty zone, $R_1 < \mathrm{d} < R_{\max}$
- Shadow-fading: log-normal of d/R_S
- Neyman-Pearson: probability of sensing (detection) for the maximum false alarm rate

- Detection threshold: individual or cooperative

- Individual: the event is considered detected if it is detected by at least one sensor
- Cooperative (e.g. All-sensor field): point p covered if all-sensor field intensity ≥ threshold

Sensing Models (3)

- Classification of sensing models:

Sensing Model	Realistic Representation	Complexity of Analysis	Application Cases
Boolean	Low	Low	Simple network geometry
Elfes'	Low/Medium	Low	Above+simple propagation
General	Medium	Low	Propagation + event signal energy
Shadow-fading	Medium/High	High	More realistic propagation
Neyman-Pearson	High	High	Gaussian noise + false alarm rate

Deployment Strategies (1)

- Strategies and scenarios:

	Deployment Strategies		
	Regular	Planned	Random
Nodes' placement	Grid-based: - Triangular lattice - Square - Hexagonal	Specific points of the area, application-dependent	Random distribution
Scenarios	Deterministic area k-coverage	Deterministic point, path & barrier coverage	Coverage & detectability of inaccessible regions

Deployment Strategies (2)

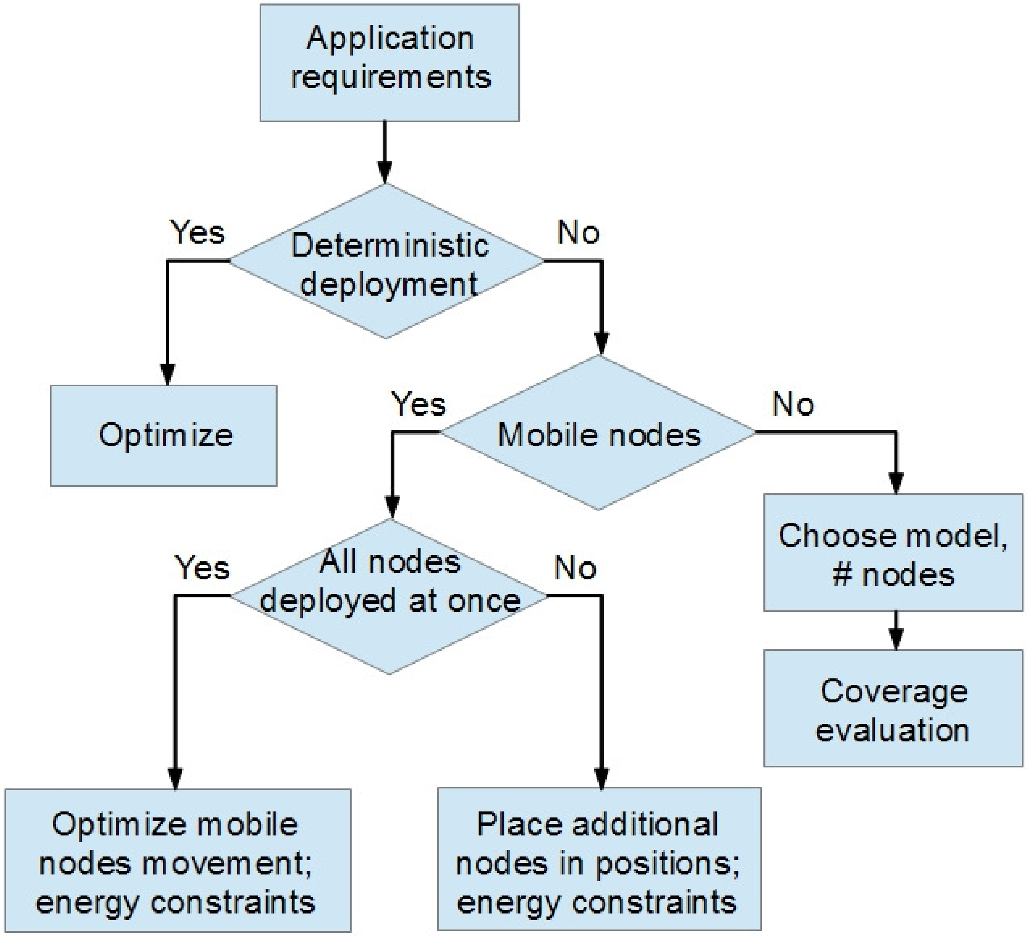
Deterministic:

- Grids: sensors at grid points or at cell center
- Determine sensors' position, coverage degree
- Analysis of grids: overlap of nodes' coverage

Stochastic:

- Random: analysis uses geometric random graphs to resemble nodes' positions
- Random: coverage in 2 or 3 dimensions
- Location of nodes: Poisson point process

Evaluation and/or Improvement of the Network Coverage



Evaluation and Improvement of the Area Coverage

- Area coverage (AC):

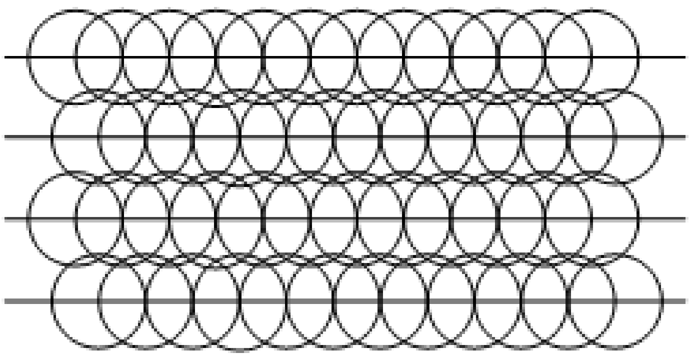
  measure of area covered by 1 or more sensors
- Gather info about entire region (monitoring)
- AC calculation:

  exact (grid positions, and by using computational geometry) vs. probabilistic
- Grid: points covered over # points
- Computational geometry:

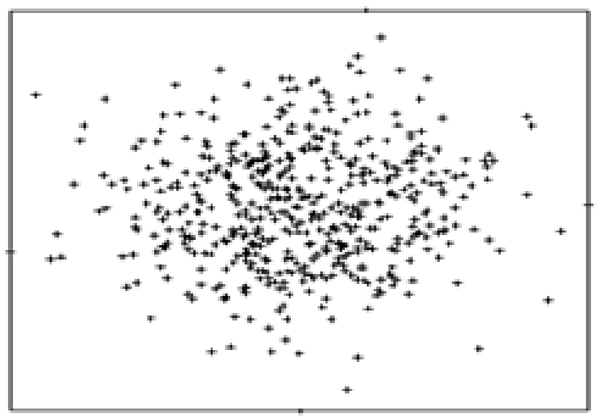
Voronoi diagram (borders equidistant from nearest points),

Delaunay triangulation (of sites; dual of Voronoi diag's)

Area Coverage (1)



Deterministic



Random

Area Coverage (2)

- Probabilistic approach:

  estimation of probability that sensing range covers P; detected by at least 1 to k nodes (k-coverage).

- Terrain-specific characteristics for sensing pattern of each node if shadow-fading / Neyman-Pearson models.

Improving AC:

- AC in deterministically deployed networks

  positioning sensors in regular manner at specific locations.

- AC of the fully mobile random network:

  moving nodes by using Force based strategies in accordance to Voronoi or Delaunay method.

Evaluation and Improvement of Detectability

- Detectability:

  probability of detecting object moving from point A to point B
- 4 contexts: path coverage,

  worst / best case coverage, barrier coverage.
- Path coverage: detectability along a given path
- Worst case/Min exposure (max breach)

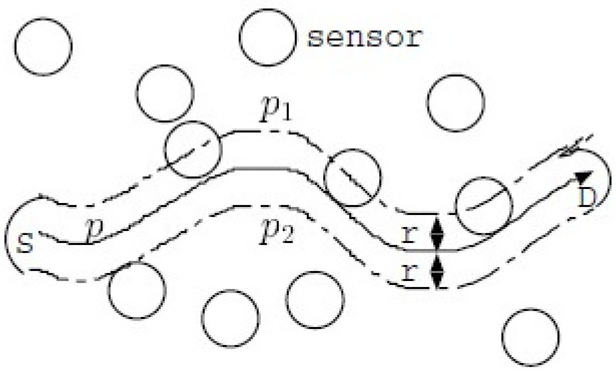
  – the path of the minimum detection probability.

  (On the edges of the Voronoi Diagram).
- Best case/Max exposure (min breach)

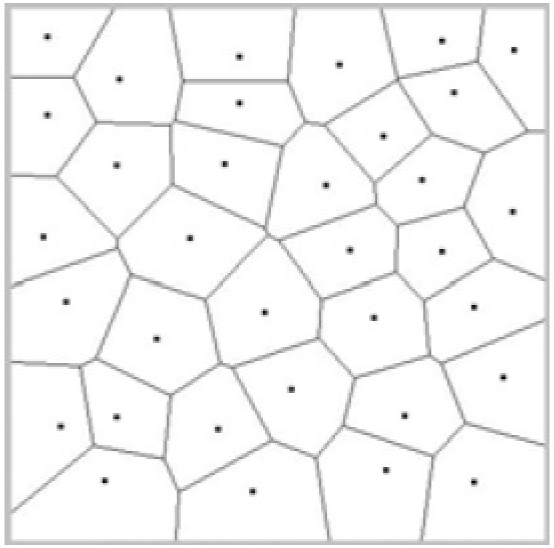
  – the path of the maximum detection probability.

  (On the edges of the Delaunay Triangulation Diagram).

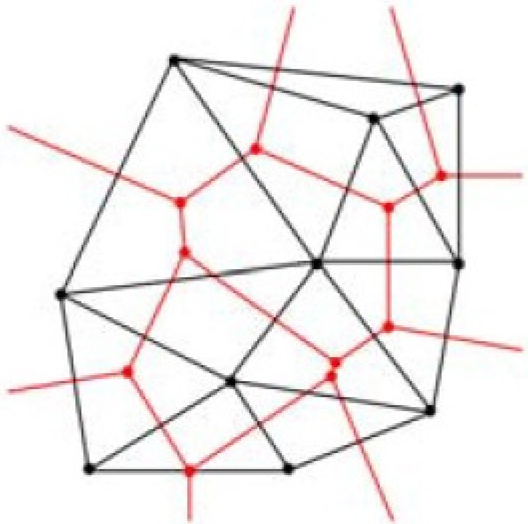
Detectability



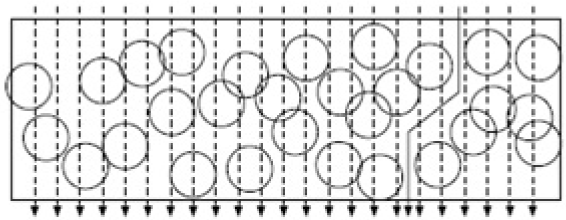
Path coverage



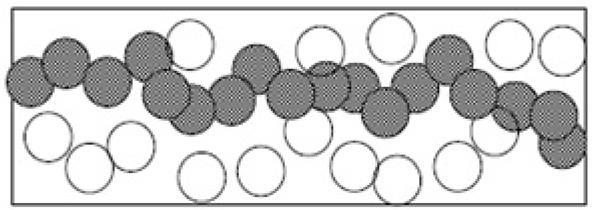
Voronoi Diagram



Delaunay Triangulation



Weak BC



Strong BC

Evaluation and Improvement of Barrier Coverage (BC)

- BC – capability of the network to detect the intruders across a specific line.
- BC: deterministic node placement – full BC.
- BC: random n.p. (e.g. inaccessible area)
  – scenarios of deploying the nodes by artillery
  and from aircraft modeled by Poisson / line-based
  distributions.
- Target: does not know / knows node positions
  – weak/strong barrier coverage.
- Only expected value for the detectability can be calculated
  in the region of finite dimensions.
- Mobile nodes are used in improving BC by mending barrier gaps.

Coverage Algorithms (1)

- Coverage degree (CD): # sensor nodes w/ sensing range covering a particular point
- Dynamically configurable CD: intrusion detect.
- Coverage and connectivity: similar radiating patterns → treated together
- When $R_C \geq 2\, R_S$, k-covered = k-connected
- Node scheduling: to conserve energy; centralized / decentralized (mostly deployed)
- Decentralized: distributed / localized

Coverage Algorithms (2)

- Comparison of existing coverage algorithms:

Algorithm	Energy min	Distributed	Localized	Degree	Reference
Perimeter Coverage	No	N/A	N/A	K ≥ 1	Huang03
Sensing Field	No	No	No	N/A	Liu03
Coverage Config Protocol	Yes	Yes	No	K ≥ 1	Wang05
Optimal Geogr. Density Control	Yes	Yes	Yes	K = 1	Zhang05
Area Dominant Set	Yes	Yes	Yes	K ≥ 1	Carle04
ASCENT	Yes	No	Yes	N/A	Cerpa04
K-Neighbor Constrained CA	No	No	Yes	K > 1	Poduri04

Conclusions

- Coverage & connectivity - key to WSN ability to detect events & communicate info to user
- Share similar signal propagation models (Binary sensing/communication model mostly)
- Optimization in WSN:

\- deterministic: covering area, forming barrier, securing a path;

\- randomly deployed: network performance / coverage improvement by using mobile nodes

- Classification of coverage algorithms

Future Work

- Machine learning on terrain characteristics
- Relate to shape & range of sensing pattern
- Measure of the # and positions of static nodes, and cost-effectiveness of using mobile nodes