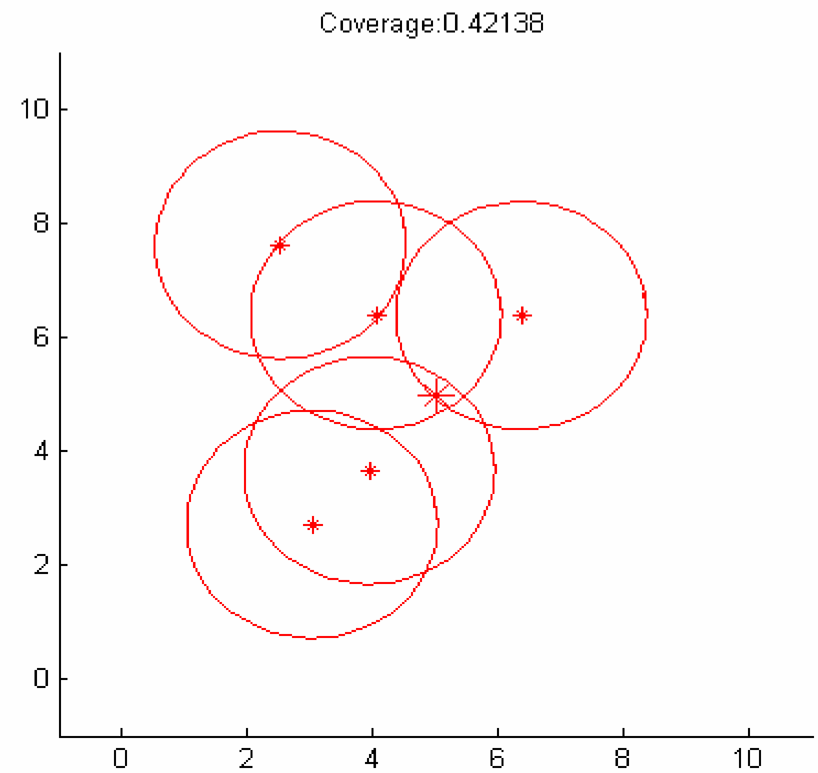
Node Placement for a Wireless Sensor Network using a Genetic Algorithm



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May 12th, 2003

Motivation

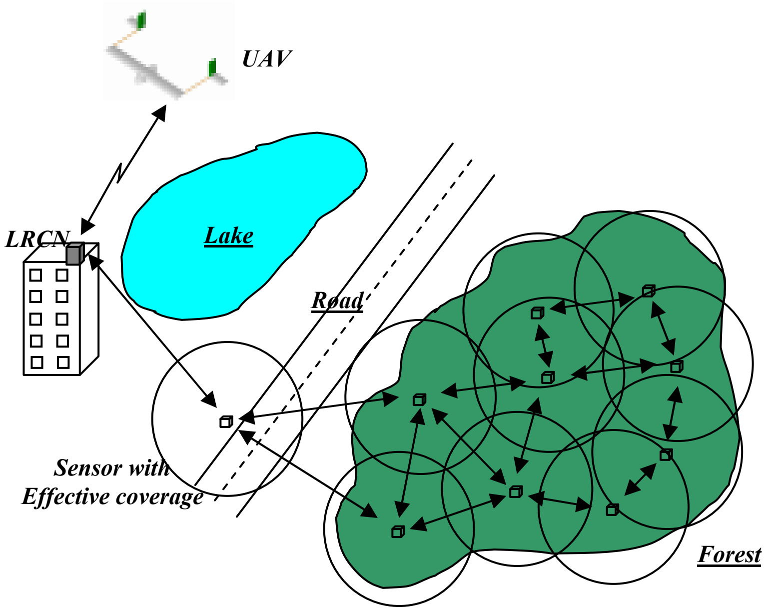
- UAVs increasingly used for variety of applications

- Need for *close up* presence for certain missions
- Necessity of removing humans from the loop
  - Hostile environment (military, chemical/biological/nuclear hazard)
  - Difficulty of access (terrain, vegetation)
  - Need for sustained presence
- Move towards unmanned automated systems

Wireless Sensor Network Description (1)

- 2 types of nodes are launched
  - *Long Range COMM Node* (LRCN)
    - Provides the high-power data relay to the UAV
  - *Sensor Nodes*
    - Perform the close up observation using the sensor
    - Transmit data via wireless medium (low energy ➔ short range)

- Mission Scenario
  - Sensors cover the area
  - They transmit their data to the LRCN (directly or via hops using other sensors)
  - The LRCN relays the network data to the UAV
  - The collected data is then sent back to the home base



Wireless Sensor Network Description (2)

- Flat square terrain
- COMM and Sensing Model
  - Constant radius
  - $R_{COMM} = R_{Sensor}$
  - 2 nodes communicates if they are within R_{COMM}
- Energy Model
  - Each node has a limited amount of energy E
  - Each data transmission has a cost ΔE

Sensor Placement Problem Formulation (1)

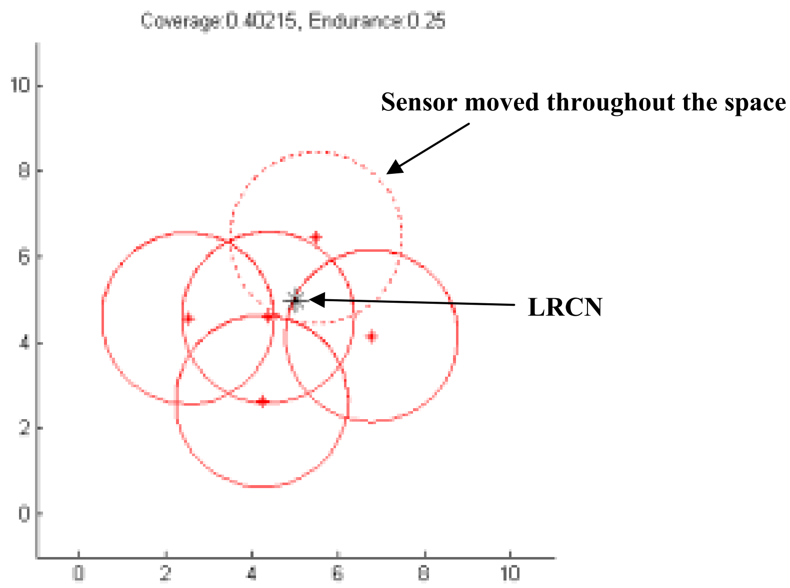
- Layout of Sensors dictates the performance of the network
  - Coverage
  - Endurance (life time)
  - Robustness to node failure (redundant COMM paths from each sensor to LRCN)
  - Robustness to launch inaccuracy
- Coverage and Endurance will be the focus of this presentation

Sensor Placement Problem Formulation (2)

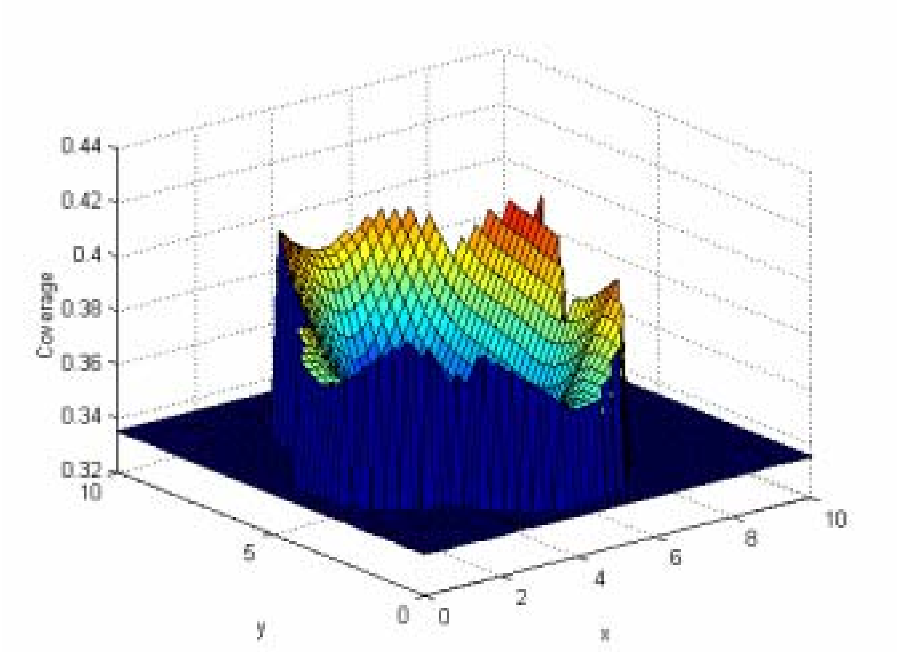
- Objectives (competing)
  - Coverage (max)
  - Endurance (max) (for multiobjective example)
- Design Vector: $\underline{X} = [x_1, y_1, \ldots, x_n, y_n]$
- Constraint
  - All Sensors must be connected to LRCN
- Parameters
  - COMM and sensing range R=2
  - Stored energy E=100 and energy draw per data transmission ΔE=1
  - Number of sensors n=5
  - Position of LRCN

Design Space Analysis

- The design space is highly non-linear



Initial network layout



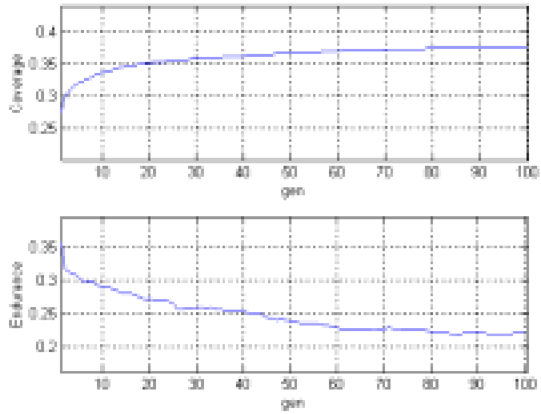
Mapping of Coverage

➔ **Genetic Algorithms are used**

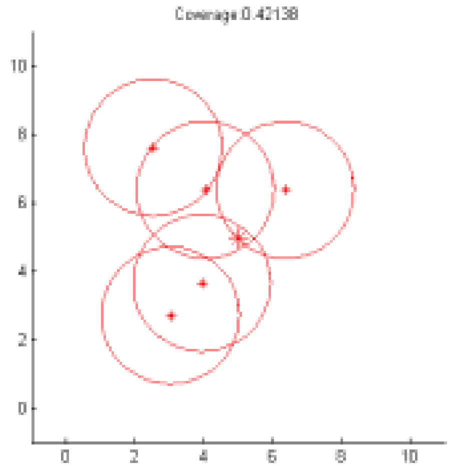
Single Objective GA

- Coverage is the only objective
- GA operators
  - No encoding/decoding
  - Every individual “mates” with another to produce N children, which are then mutated at a rate P_m
  - Selection is performed among Parents and Children using a deterministic elitist scheme (outperformed roulette wheel and binary tournament selection). Disadvantage: early homogenization of population ➔ use mutation rate of 0.2 to maintain diversity
- Simulation results for 100 generations, a population size of 60 and a mutation rate of 0.2

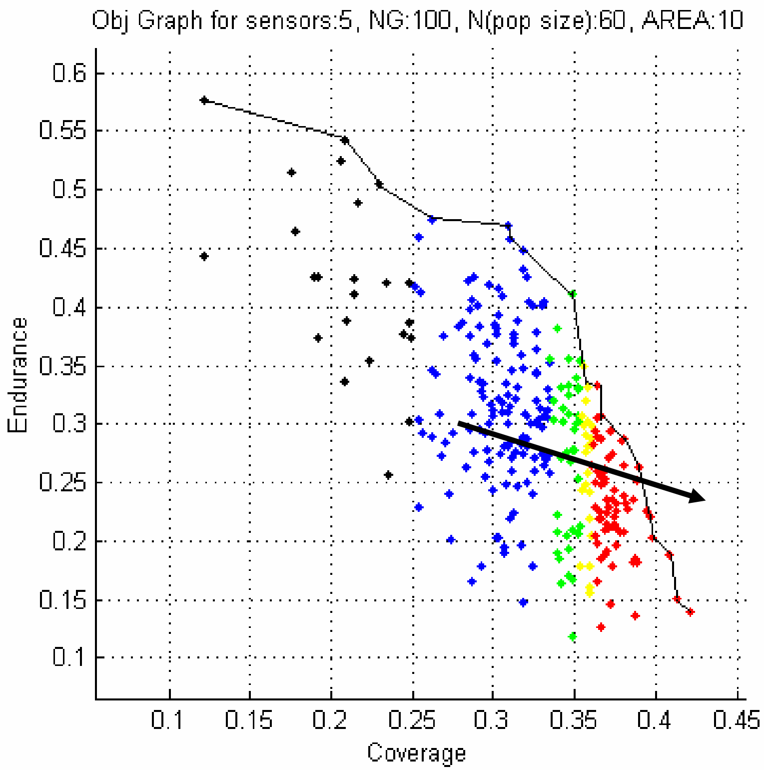
SOGA results



Graph of Coverage (top) and Endurance (bottom) versus generation



Network with best Coverage



Objectives graph (Coverage versus Endurance)

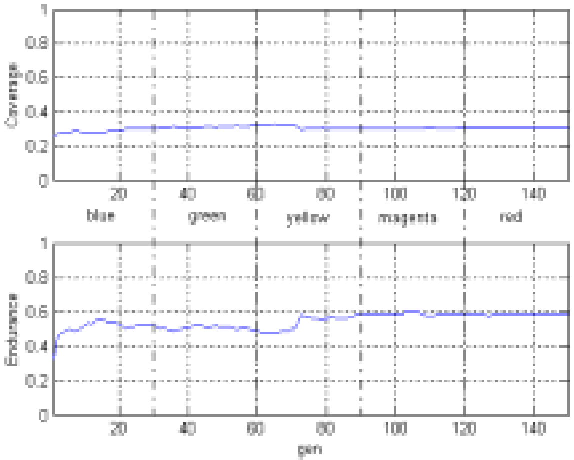
Multi Objective GA

- Coverage and Endurance are the objectives

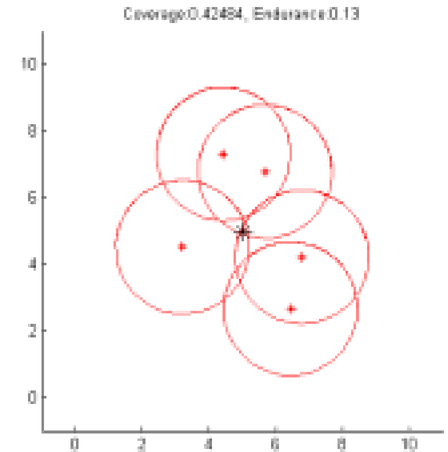
- Selection is performed among Parents and Children using again a deterministic elitist scheme. The fitness for the selection is based on Pareto dominance of each individual. The N best ranked are passed on to the next generation

- Simulation results for 150 generations, a population size of 60 and a mutation rate of 0.2

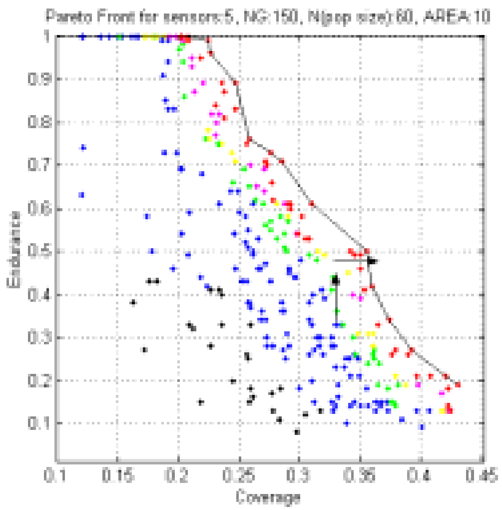
MOGA results



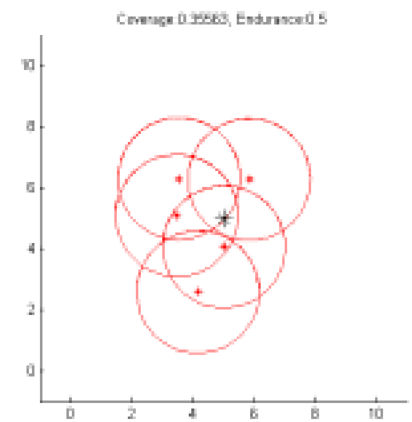
Graph of Coverage (top) and Endurance (bottom) versus generation



Network with best Coverage



Objectives graph (Coverage versus Endurance)



Network with good Coverage and good Endurance

Conclusions and Future Work

- MOGA with elitist selection enables well-populated PF which is useful for providing the decision maker with Pareto-best designs
- Need to incorporate more realistic terrain to evaluate the usefulness of this method
- Crossover schemes should be improved to minimize destructive mating (mating restrictions?)
- Develop a tool for refining the raw GA output – gradient or greedy method (hybrid optimization)

Thank You!

References:

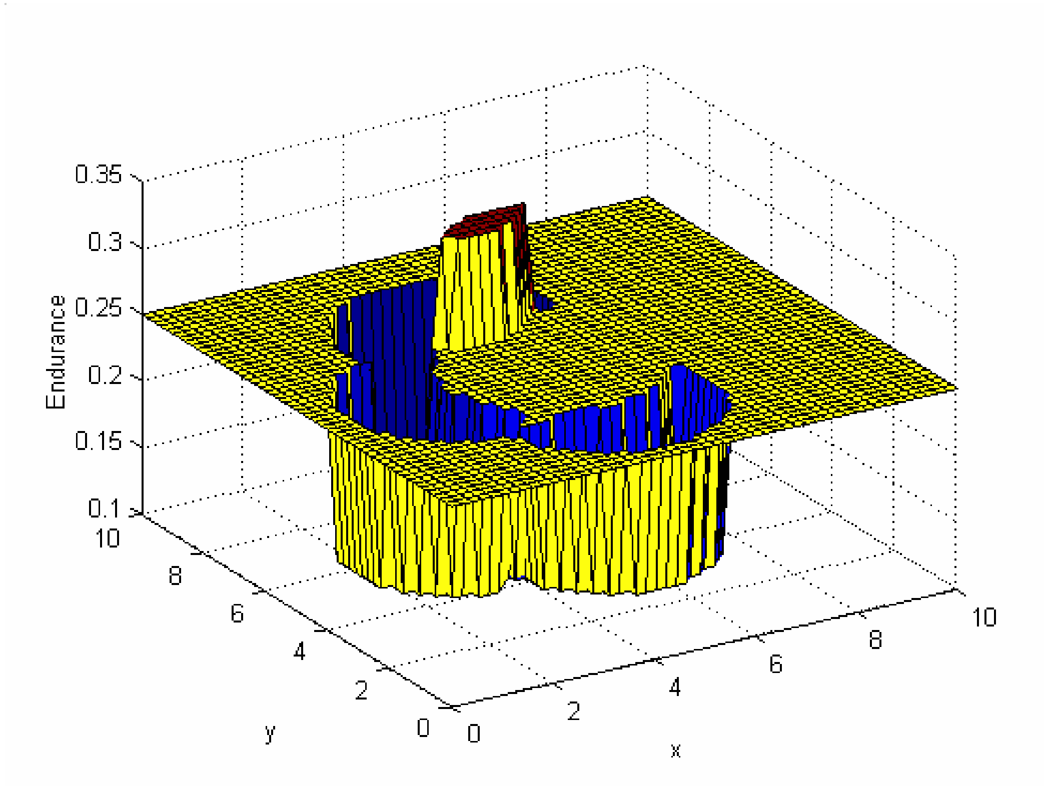
[1] J. Nemeroff, L. Garcia, D. Hampel and S. DiPierro, "Application of Sensor Network Communications", *IEEE,* 2001.

[2] T. Cormen, "Introduction to Algorithms", MIT Press, Cambridge MA, 2001.

[3] C. M. Fonseca and P. J. Fleming, "Genetic Algorithms for Multiobjective Optimization: Formulation, Discussion and Generalization", in *Genetic Algorithms: Proc. Fifth International Conference*, pp 416-423, Morgan Kaufmann, 1993.

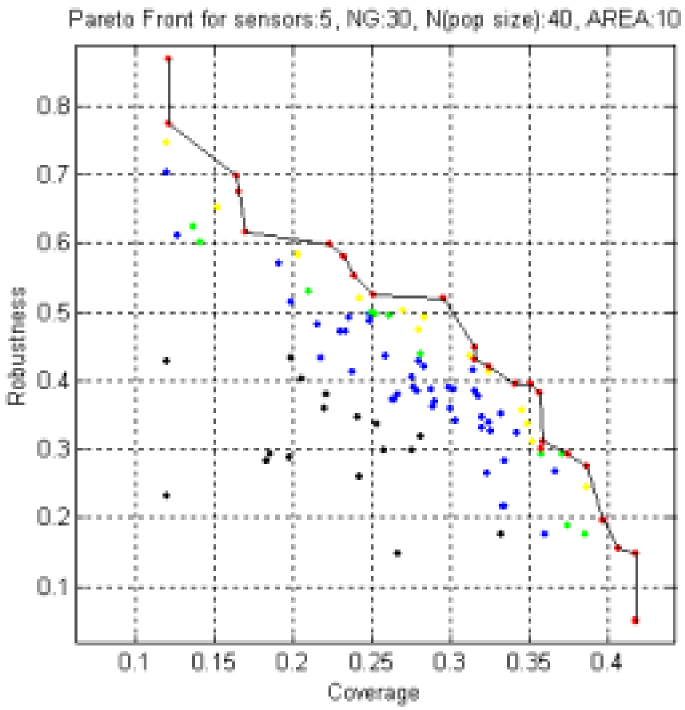
[4] C. A. Coello Coello and alt. "Evolutionary Algorithms for Solving Multi-Objective Problems", Kluwer Academic Publishers, New York, 2002.

[4] S. M. Allen, D. Evans, S. Hurley and R. M. Whitaker, "Communications Network Design with Mobility Characteristics", *IEEE*, 2002.

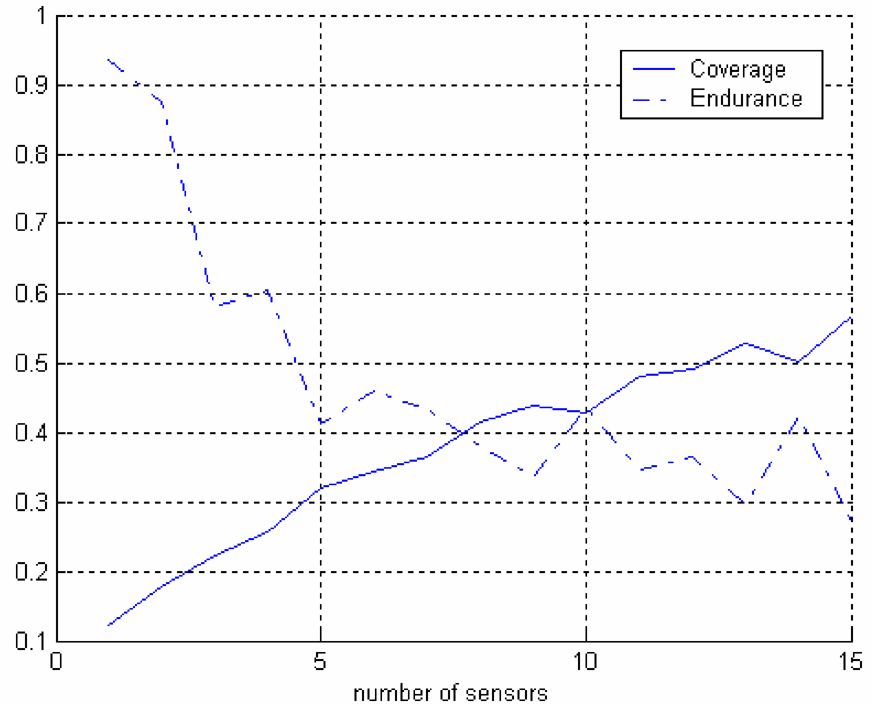


Mapping of Endurance

MOGA with Robustness



Trade-off Study



Average Coverage and Endurance versus number of sensors