Maneuverable Relays to Improve Energy Efficiency in Sensor Networks

Stephan Eidenbenz, Lukas Kroc, James P. Smith
Los Alamos National Laboratory
LA-UR-04-6953

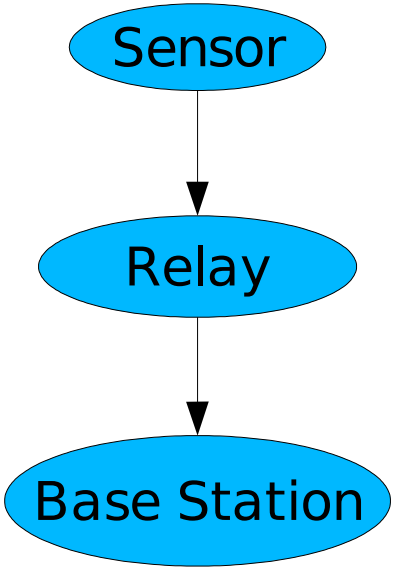
NNSA

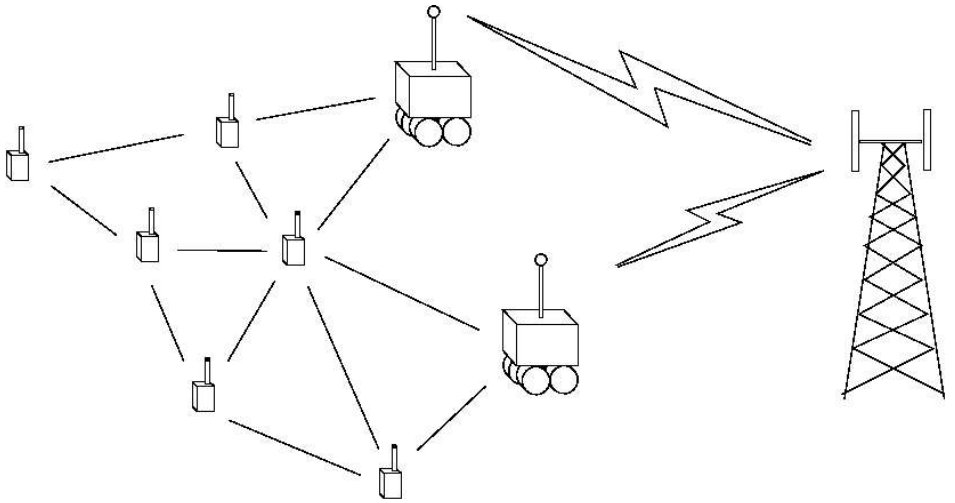
Los Alamos

Introduction

- One-sink data flow
- Energy efficiency targeted in many ways
  - Specialized routing algorithms
  - Hierarchical organization
  - Power management techniques
- Our approach
  - Hierarchy with specialized hardware

Our Approach





- Sensors know their positions
- Relays are maneuverable, can be positioned to desired places, or are mobile

Goal

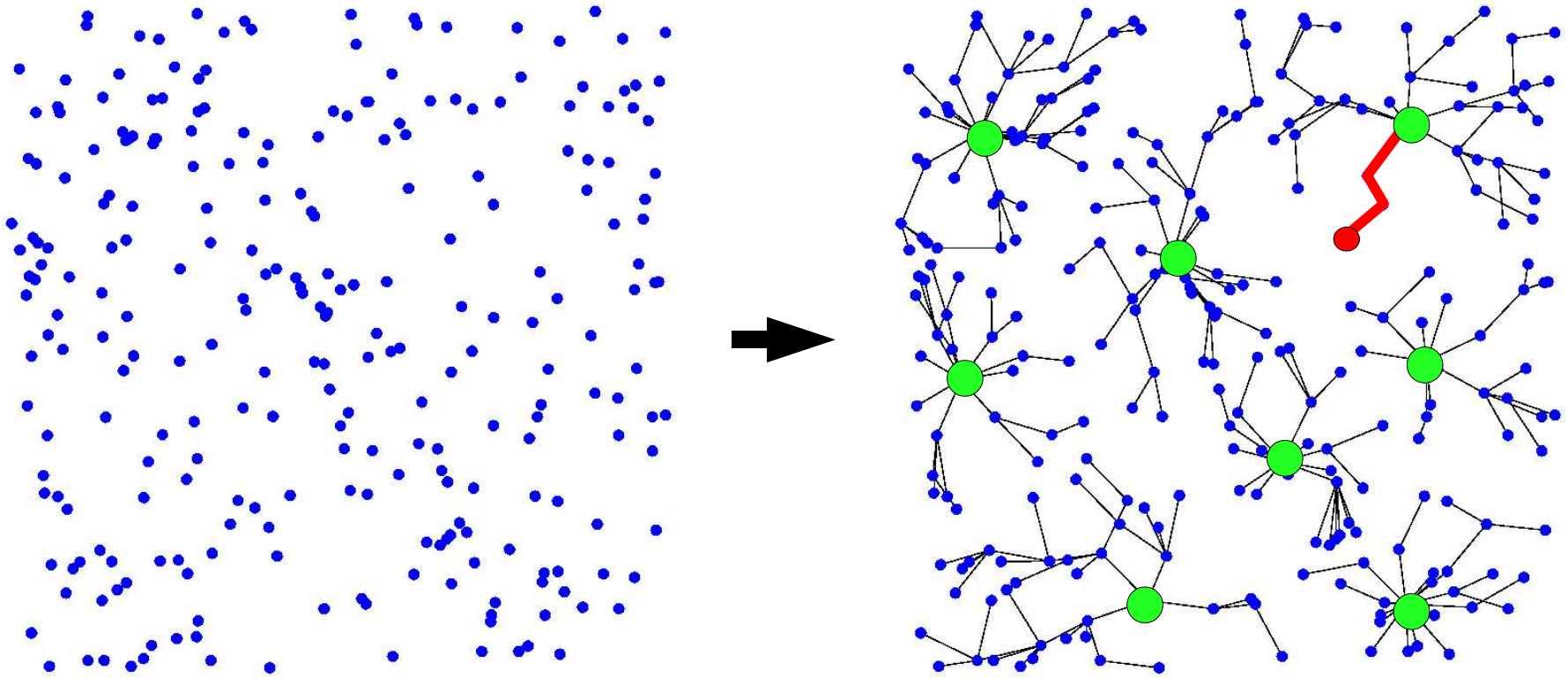
- Position relays so that the energy consumption is minimized

$$E_S = \sum_{i=1}^{n} f_i \cdot d_i \cdot E_U$$

f - # packets generated
d - hop count to relay
E_U - energy per one transmission

- d is influenced by the relays positions, can be used to minimize E_s

Goal Example



$$E_S = \sum_{i=1}^{n} f_i \cdot d_i \cdot E_U$$

Network Usage Algorithm

1. Deploy sensors, compute their positions
2. Gather sensor positions at base station
3. Compute suitable relay positions
4. Deploy relays
5. Relays inform sensors of their positions, sensors know where to send data
6. Data traffic routed along the shortest paths

Relay Positioning Problem

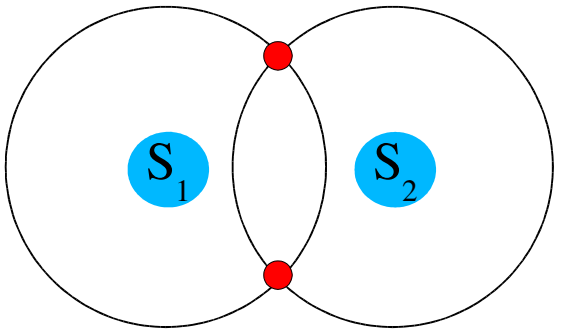
- Definition
  - Given n positions of sensors in the plane, find k relay positions such that the resulting energy usage E_s is minimum.
- Results
  - NP-complete

    => heuristics needed for large instances
  - Empirical study of various heuristic approaches

    => cost/quality trade-off

NP-completeness of Relay Positioning

- Decision version: given energy threshold E_T, can we place the relays so that $E_s \leq E_T$?
  - in NP: optimum solution exists in which relays are placed at intersections of sensor radii circles

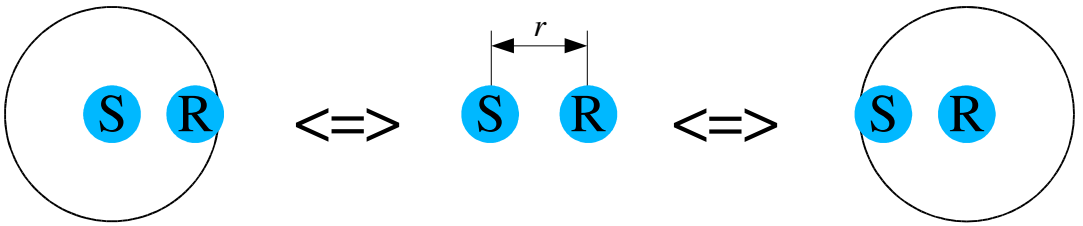


- Reduction from Geometric Covering by Discs
  - Instance: set *P* of integer-coordinate points in the plane, positive integers *r* and *K*
  - Question: Can the points in *P* be covered by *K* discs of radius *r*.

NP-completeness of Relay Positioning

- Reduction:
  - Sensors placed at points from P, ranges = r
  - f_i, E_U set to 1 => $E_S = \sum d_i$ (hop-count path lengths)
  - $E_T = |P|$ (each sensor allowed only one hop to a relay)

  => (we can place K relays so that $E_s \leq E_T$) iff
  (we can cover P with K discs with radius r)

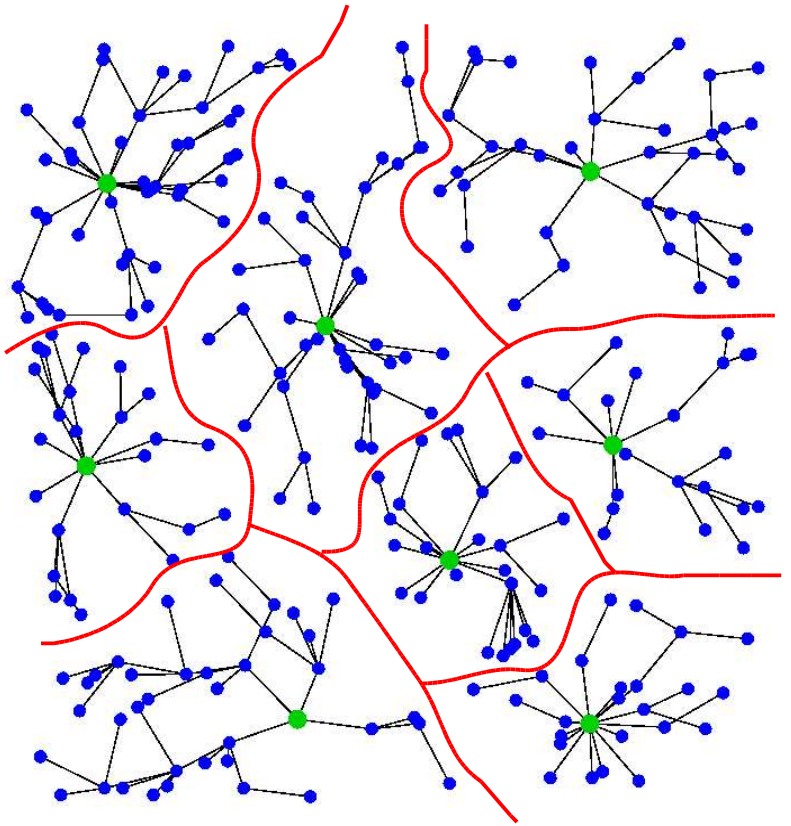


Heuristic Approaches

- Main assumptions
  - Sensors: stationary
  - Data load: uniform

$$E_S = \sum_{i=1}^{n} d_i$$

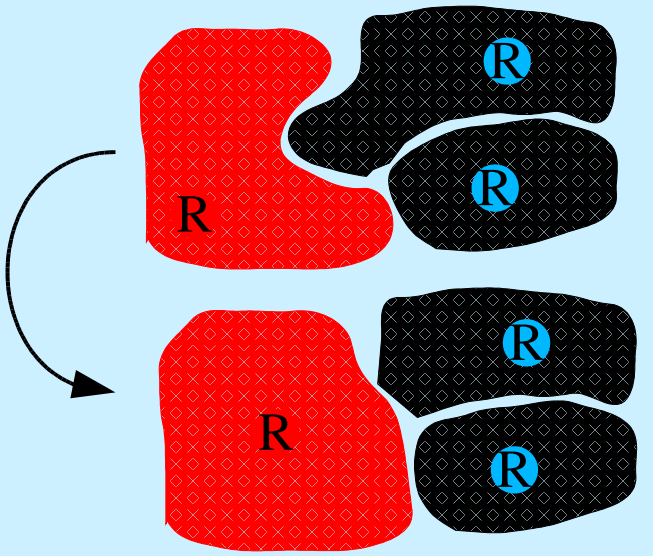
- Positioning relays can be viewed as clustering sensors



Clustering Algorithms

- Locally Improving
  - k-means
  - bottom-up
- Globally Improving
  - k-global
  - greedy

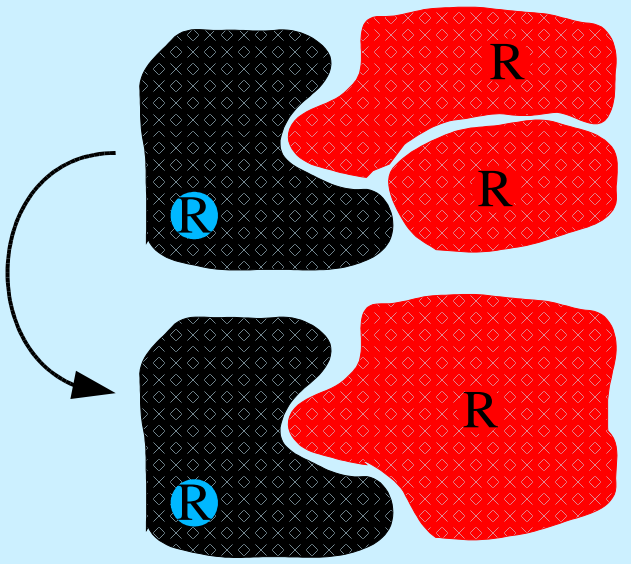
- Place *k* relays randomly
- Repeat: center a relay in its cluster



Clustering Algorithms

- Locally Improving
  - k-means
  - bottom-up
- Globally Improving
  - k-global
  - greedy

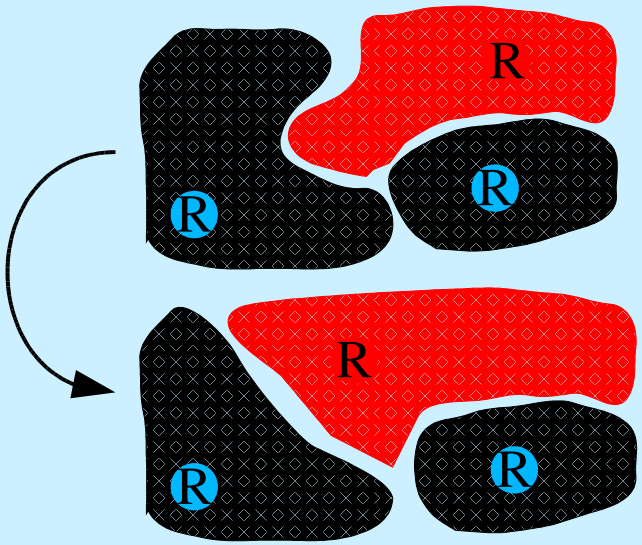
- Each sensor is a cluster
- Repeat: combine two closest clusters



Clustering Algorithms

- Locally Improving
  - k-means
  - bottom-up
- Globally Improving
  - k-global
  - greedy

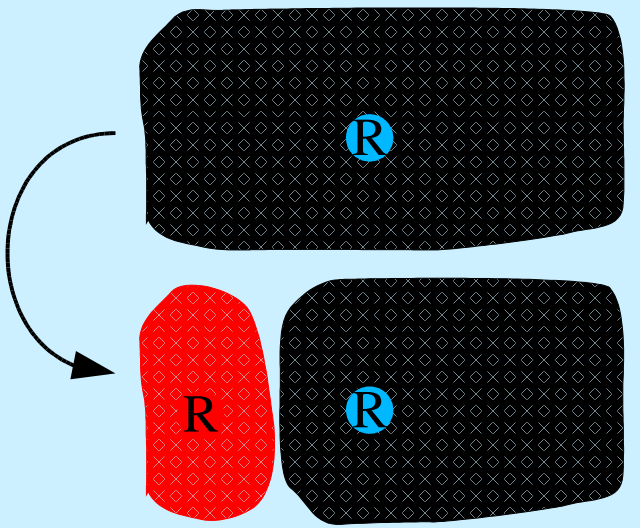
- Place *k* relays randomly
- Repeat: place a sensor to minimize overall cost



Clustering Algorithms

- Locally Improving
  - k-means
  - bottom-up
- Globally Improving
  - k-global
  - greedy

- Place relays one by one, to a globally optimal positions



Clustering Algorithms

- Distance definitions
  - Euclid distance
    - Easy to compute, may not approximate true cost well
  - Hop-count
    - Corresponds to the true path length, costly to compute
- Possible relay positions set
  - Sensor positions
    - Small $O(n)$, but may not contain any optimal solution
  - Plus radii intersection points
    - Large $O(n^2)$, but must contain an optimal solution

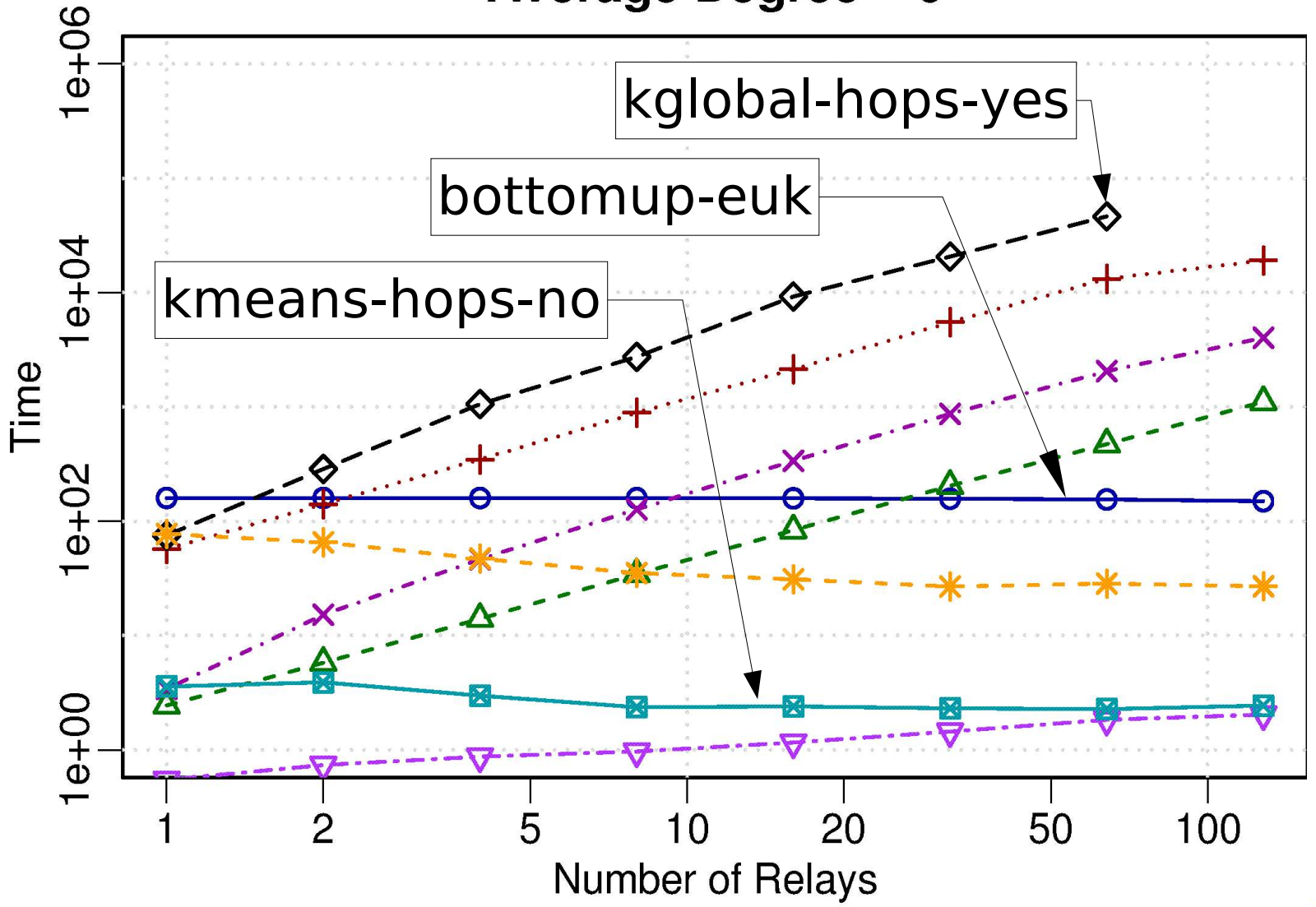
Simulation Setup

	Local		Global	
	k-means	bottom-up	k-global	greedy
Euclid	X	X		
Hops with	X		X	X
Hops without	X		X	X

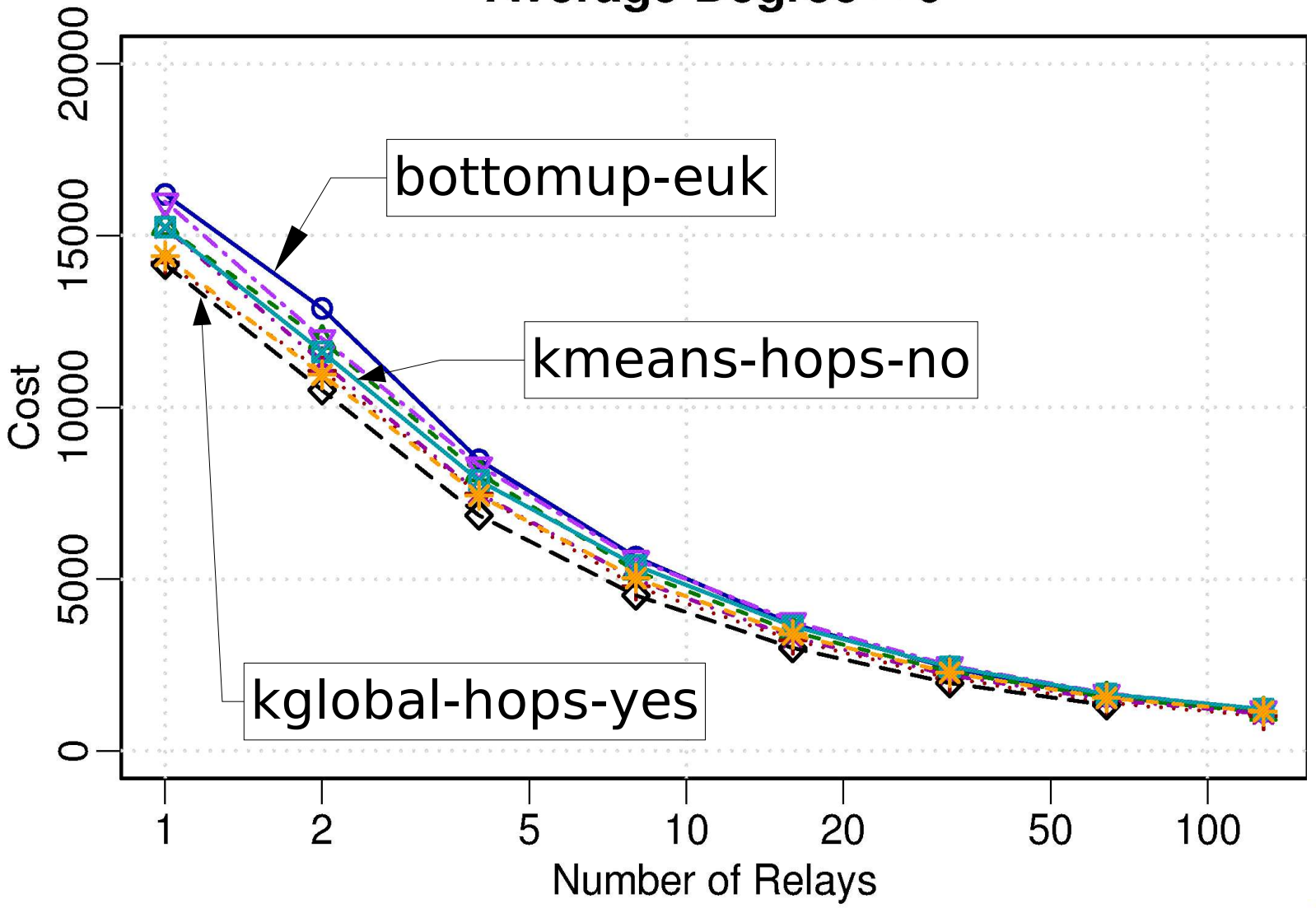
- 1024 sensors, 1...128 relays, 6...24 average connectivity degree
- Greedy with intersections is guaranteed to find a solution within ~1.58 of the optimum

  => small differences in solution quality expected

Simulation Results



Simulation Results



NNSA

Los Alamos

Conclusions

- Problem of positioning maneuverable relays presented
  - Shown to be NP-complete
  - Performance of various heuristics compared
- Computationally expensive methods bring some improvements

- Future work
  - Minimizing maximum energy use per node
  - Self-positioning relays moving towards regions with high traffic density