Balanced-energy Sleep Scheduling Scheme for High Density Cluster-based Sensor Networks

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Motivation

- Consider:
  - Sensor network with randomly distributed sensors
  - Application: provide coverage of area for surveillance (QoS)
- Assumption:
  - Sensor density is higher than necessary for meeting QoS

Motivation (cont.)

- Characteristics of sensor networks
  - Low energy
  - Low bandwidth
- Networks expected to last for months unattended
  - Energy-efficiency is crucial
- Exploit redundancy by powering down unnecessary sensors
  - Save energy for later when nodes are more important

→ Sleep Scheduling Problem: Which sensors to power down?

Cluster-based Networks

- Base station cannot manage sensors directly
- Clustering provides framework for
  - Local control
  - Resource management
  - Channel access
  - Data fusion
- Within a cluster, how to set nodes to sleep?

Assumptions

- Dense, static, circular clusters
- Variable transmission power to reach cluster head
  - x = distance from sensor to cluster head
- Nodes distributed as 2D Poisson point process
- Energy savings is expected energy consumption were the node awake

$$E_{active}(x) = l \cdot k_1 \cdot [\max(x_{\min}, x)]^g + k_2$$

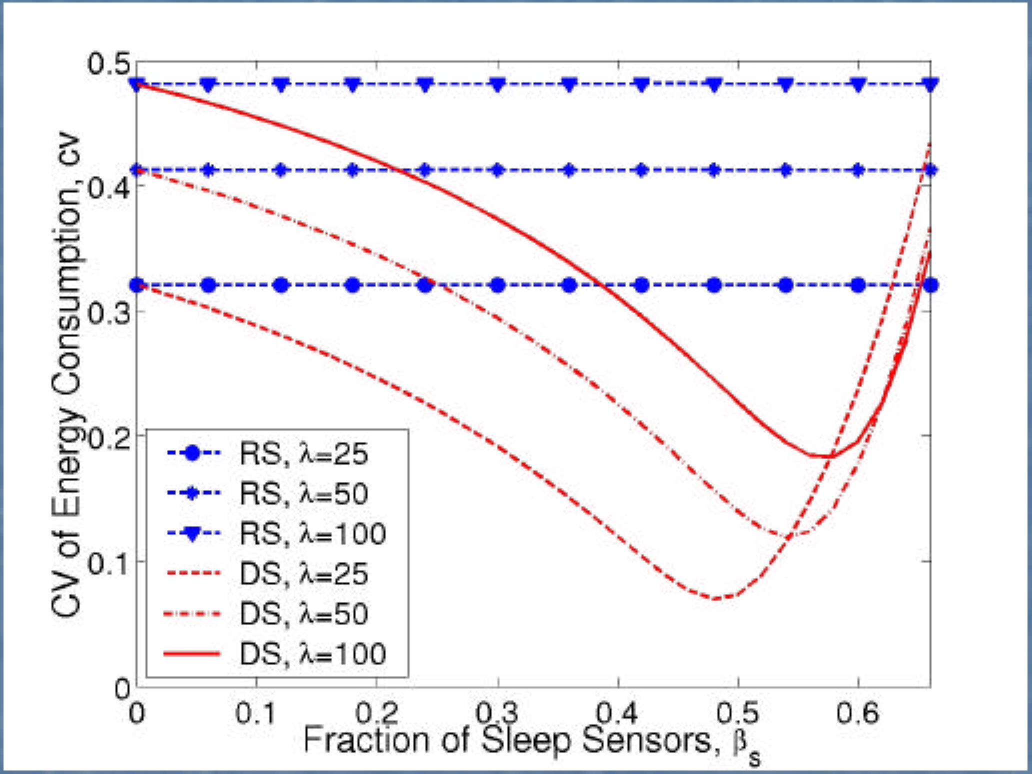
Initial Scheduling Techniques

- Randomized scheduling (RS)
  - Randomly put sensors to sleep
  - Each sensor sleeps with probability $p = b_s < 1$
- Distance-based scheduling (DS)
  - Probability p linearly related to x
  - Sensors further from cluster head put to sleep with higher probability

$$p(x) = \frac{3b_s x}{2R} \qquad 0 \le x \le R$$

Coefficient of Variation

# nodes	500
k_1	10^{-6} J/pkt/m^2
k_2	0.1 J/sec
x_{min}	10 m
λ	25, 50, 100 pkt/sec
R	100 m
γ	2



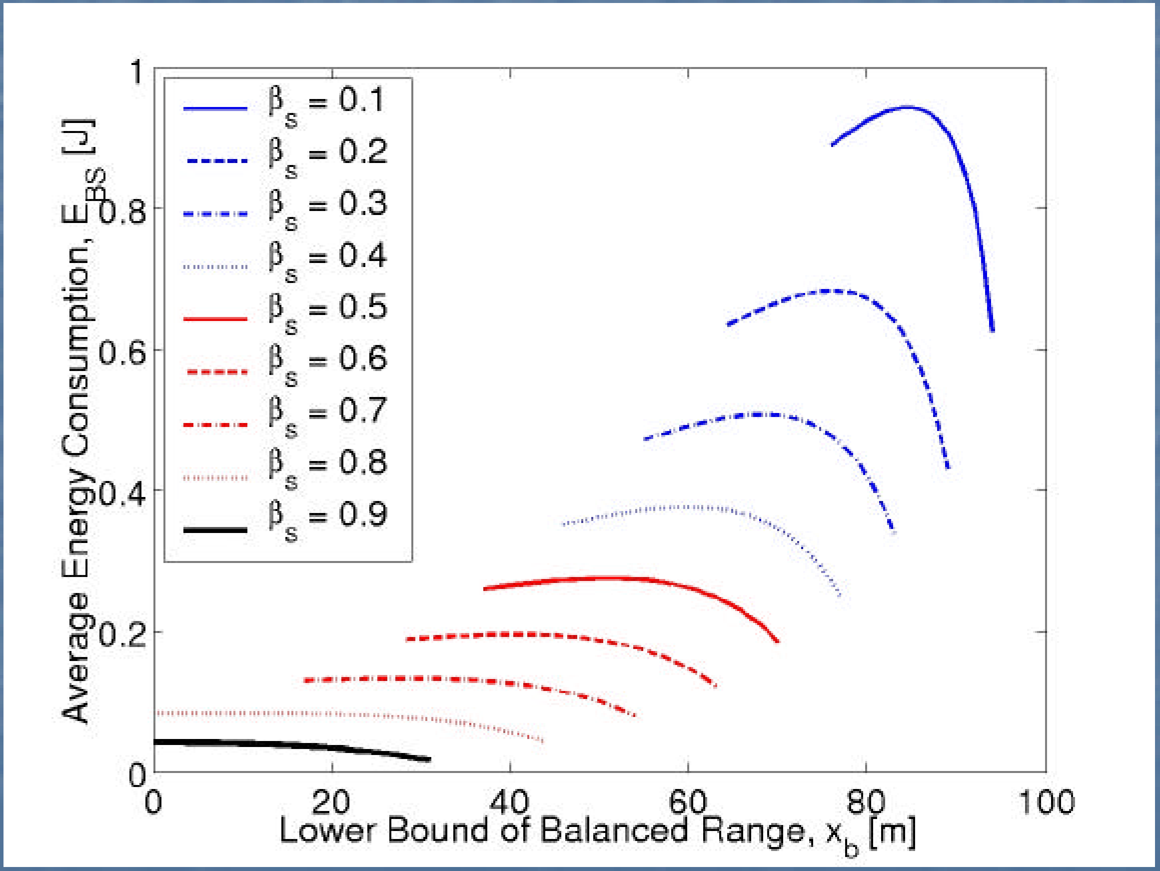
- Analytically determine coefficient of variation of energy consumption for RS and DS

Balanced-Energy Scheduling (BS)

- p(x) chosen so nodes consume same amount of energy, on average
- Let $E_{BS}(x)$ be expected energy consumption of a node at distance x from cluster head
- Find p(x) such that $E_{BS}(x)$ does not depend on x
  - Can only energy balance certain portion b_b of nodes
  - Nodes close to cluster head not energy balanced

$$E_{BS}(x) = [1 - p(x)]E_{active}(x) = E_{BS}^{(b)} \qquad x_b \le x \le R$$

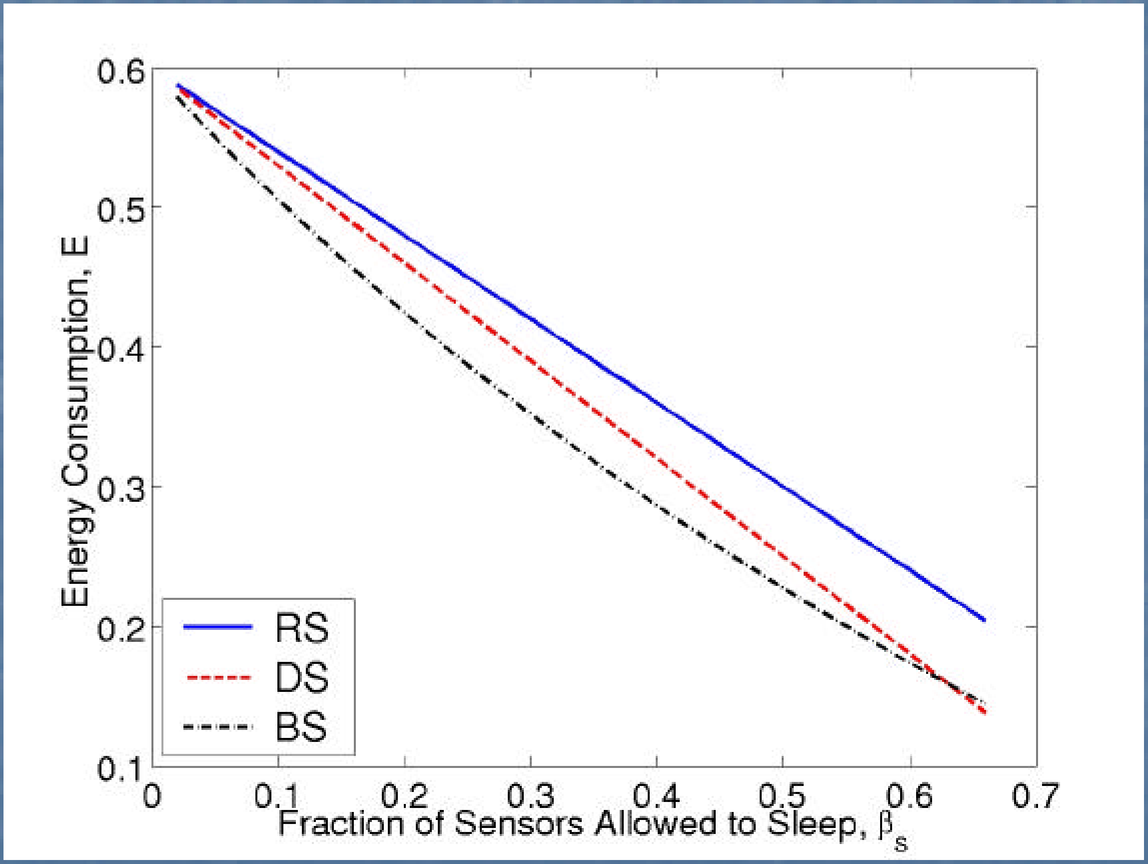
Results



β_s = 0.1
β_s = 0.2
β_s = 0.3
β_s = 0.4
β_s = 0.5
β_s = 0.6
β_s = 0.7
β_s = 0.8
β_s = 0.9
Average Energy Consumption, E_{BS} [J]
0
0.2
0.4
0.6
0.8
1
0
20
40
60
80
100
Lower Bound of Balanced Range, x_b [m]

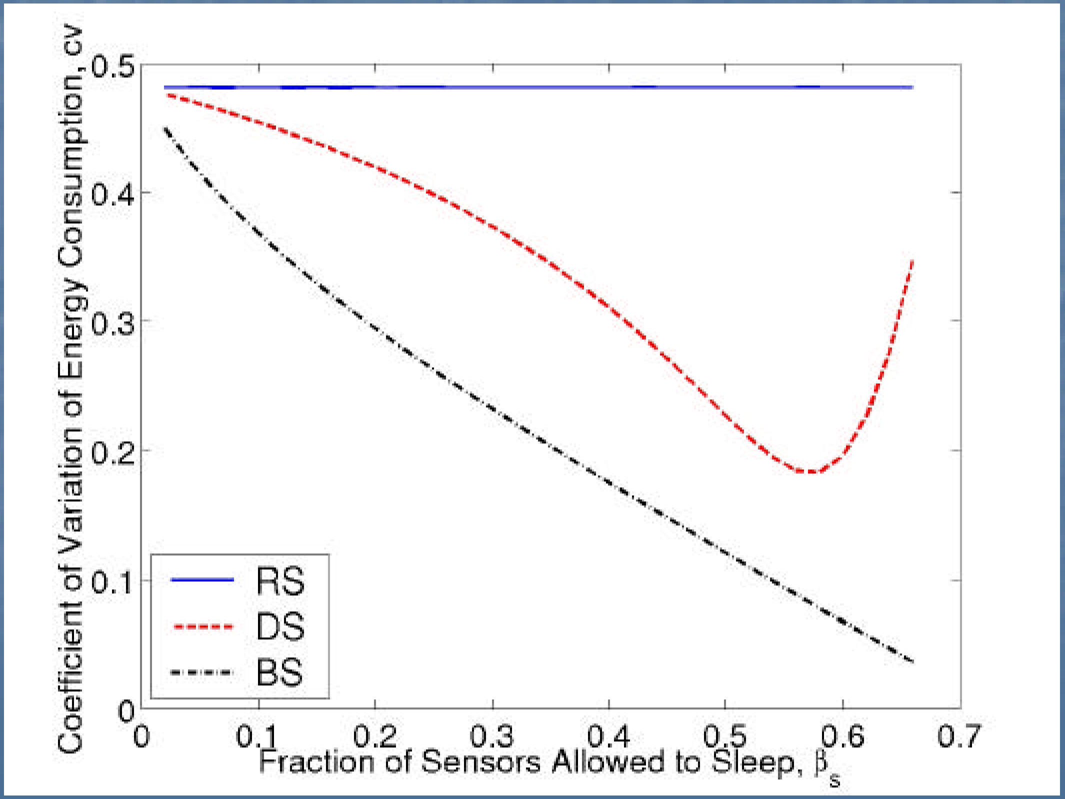
Performance Evaluation

- Analytically determine expected energy consumption
- λ = 100 pkts/s



Performance Evaluation (cont.)

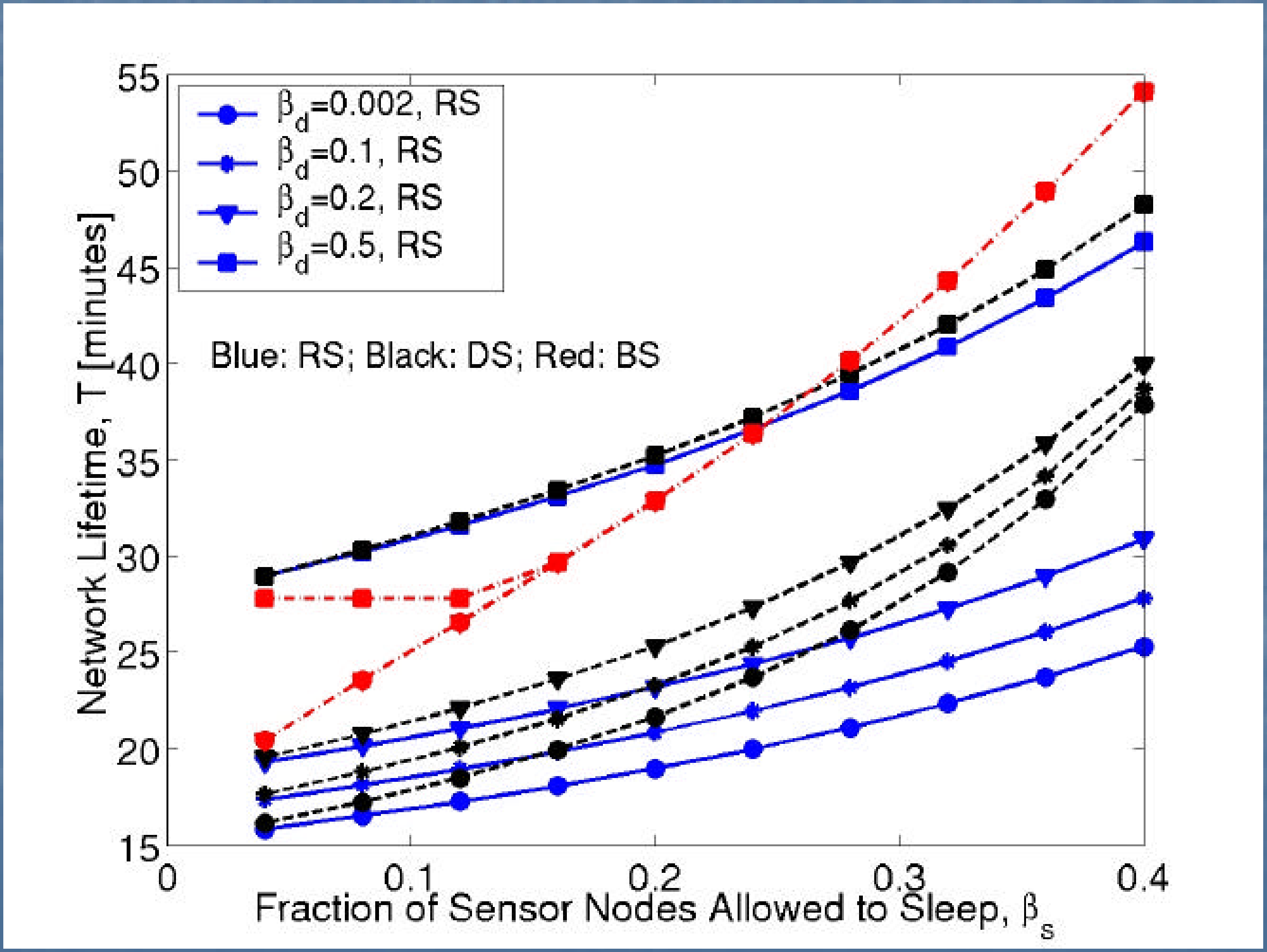
- BS achieves goal of lower coefficient of variation



Network Lifetime

- T(b_d) = time when b_d fraction of sensors run out of energy
- Initial sensor energy = Ψ
- For BS, b_b fraction of nodes consume same energy
  - When $b_d = b_b$ $$T_{BS}(b_d) = \frac{\Psi}{E_{BS}^{(b)}}$$
- In RS, nodes farther away consume more energy
  - Run out of energy faster than closer nodes
- In DS, network lifetime calculated numerically

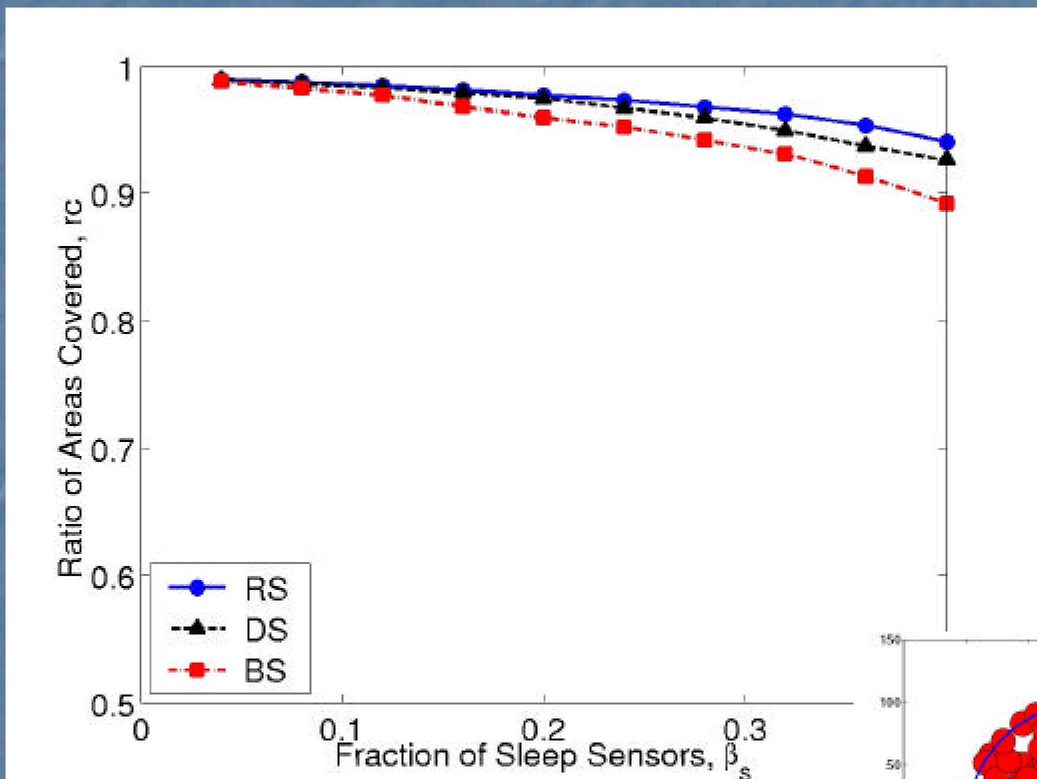
Lifetime Results



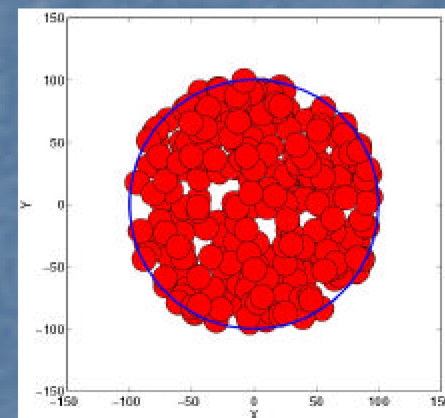
Lifetime Results (cont.)

- BS has 70% (150%) longer lifetime than DS (RS) for $b_d = 0.1$
- BS has better lifetime than DS and RS for all points except $b_d = 0.5$ and $b_s < 0.27$
  - Small b_s → fewer sensors energy balanced
  - 50% sensors run out of energy quickly

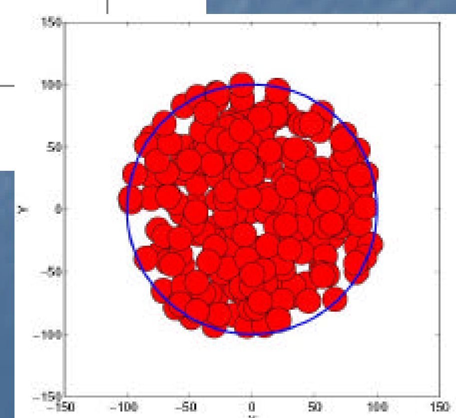
Sensing Coverage



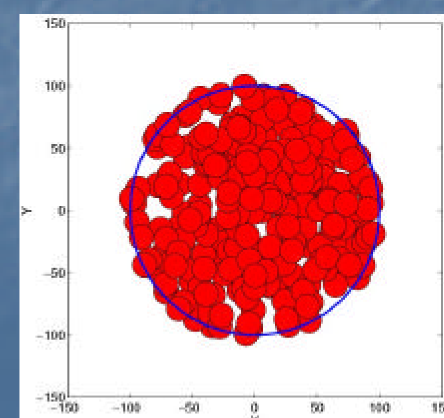
RS



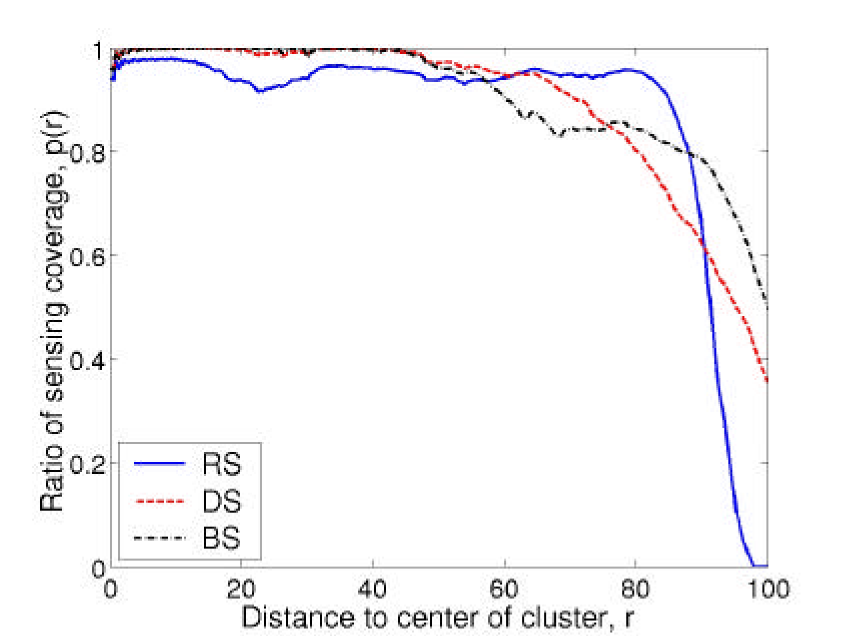
BS



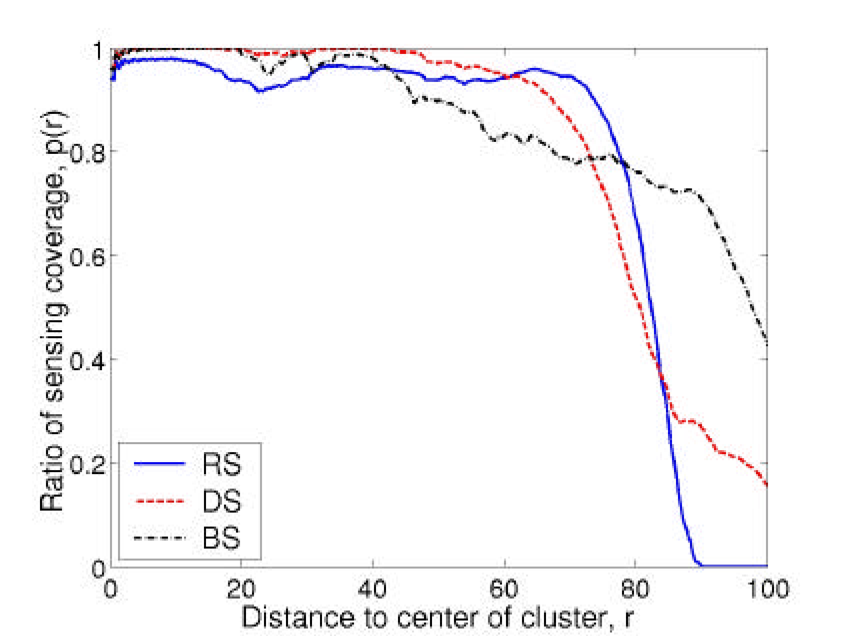
DS



Sensing Coverage Distribution

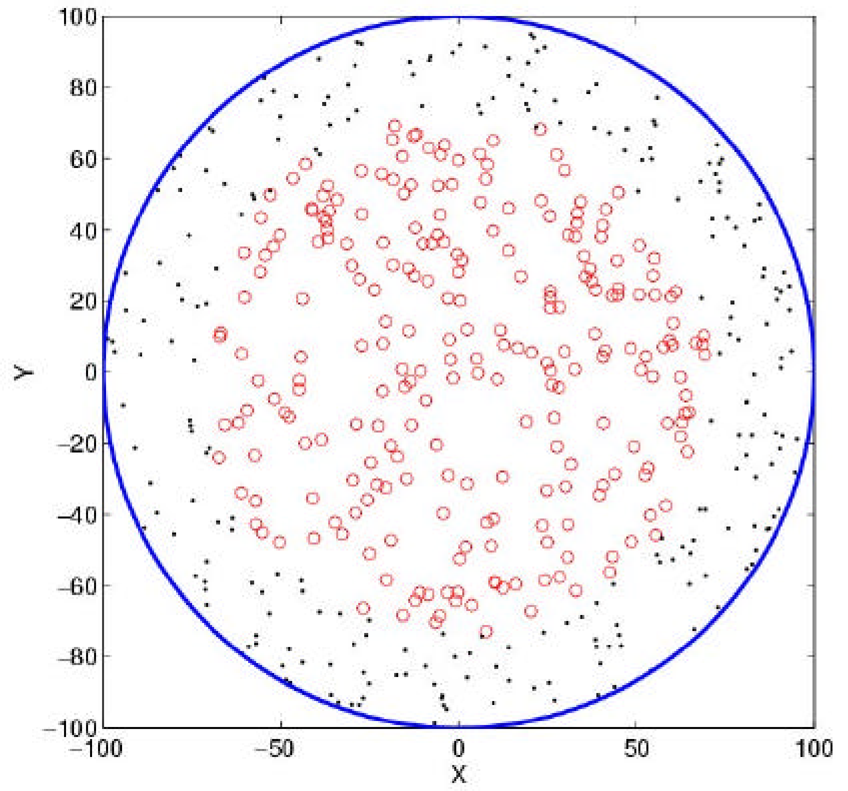


Initial sensing coverage distribution

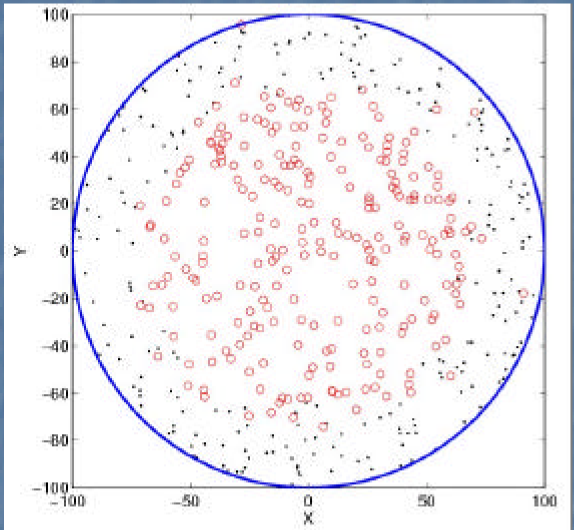


Sensing coverage distribution after 40% nodes run out of energy

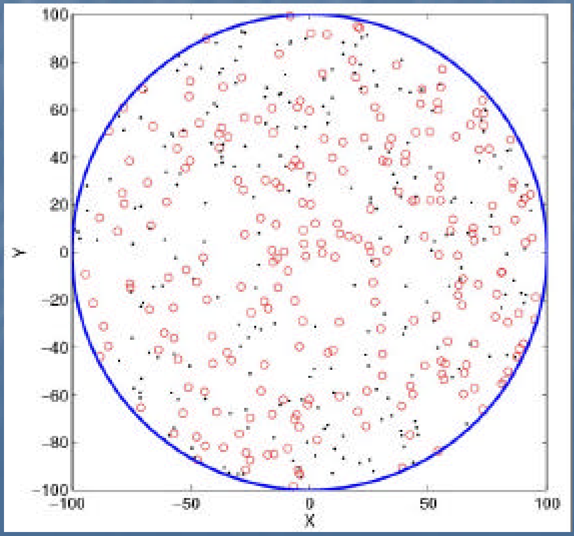
50% Sensors Remaining



RS



DS



BS

Conclusions

- Sleep scheduling important to extend network lifetime
- Balanced-energy scheduling effective in extending lifetime while maintaining coverage
- Future work
  - Explore different initial energies
  - Dynamically changing clusters and cluster heads to balance energy among all nodes