Collaborative Processing in Sensor Networ

Lecture 3 - Clustering and Sensor Selectio

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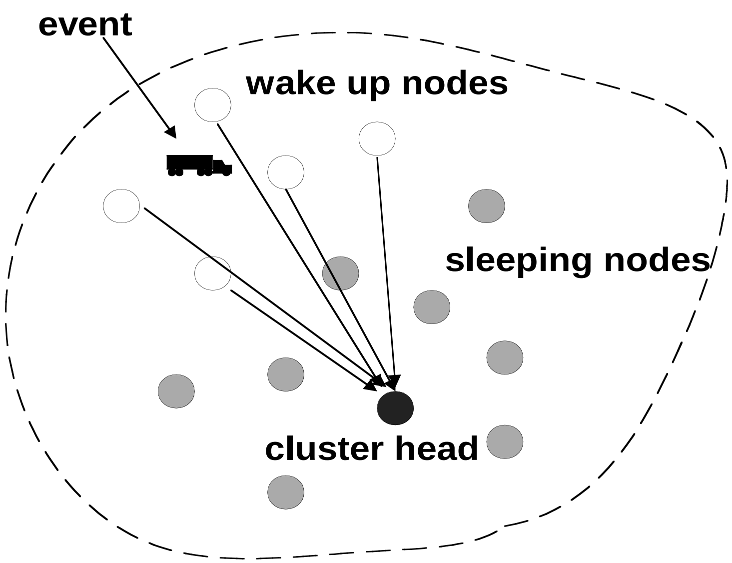
Research Focus - Recap

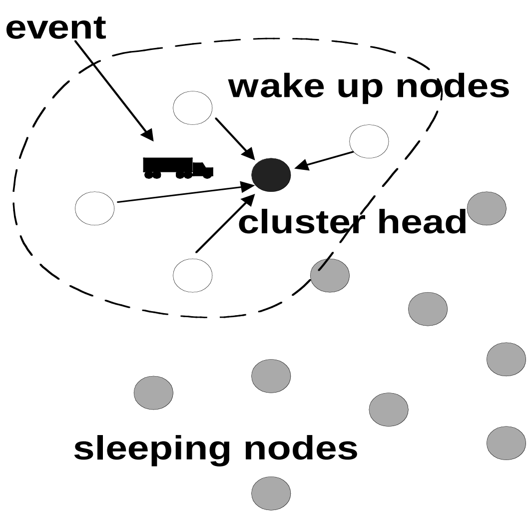
- Develop energy-efficient collaborative processing algorithms with fault tolerance in sensor networks
  - Where to perform collaboration?
    - Computing paradigms
  - Who should participate in the collaboration?
    - Reactive clustering protocols
    - Sensor selection protocols
  - How to conduct collaboration?
    - In-network processing
    - Self deployment

Clustering Protocols

Proactive



Reactive



- Clusters formed in advance
- Unnecessary radio transmission
- Large transmission power to reach cluster head
- Energy-inefficient

- Clusters formation driven by events
- Localized protocol
- Less transmission power to reach clust head
- Energy-efficient

Related Work

AICIP RESEAR

- SPAN and GAF
  - The positions of nodes are known *a-priori*
- LEACH
  - Balancing energy consumption by randomly choosing a cluster head
- CMLDA
  - Form clusters to maximize network lifetime while doing data collection
- DD
  - Directed diffusion

Decentralized Reactive Clustering (DRC)

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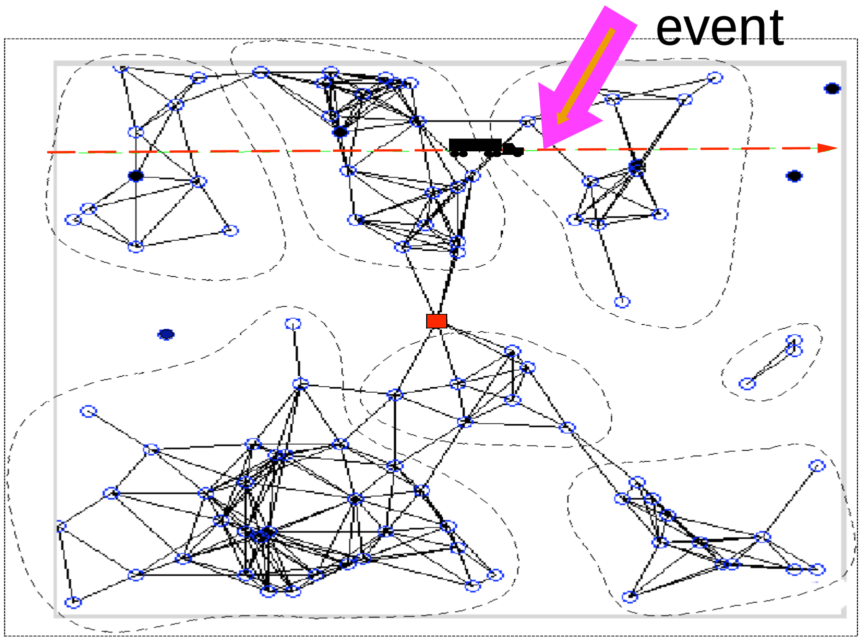
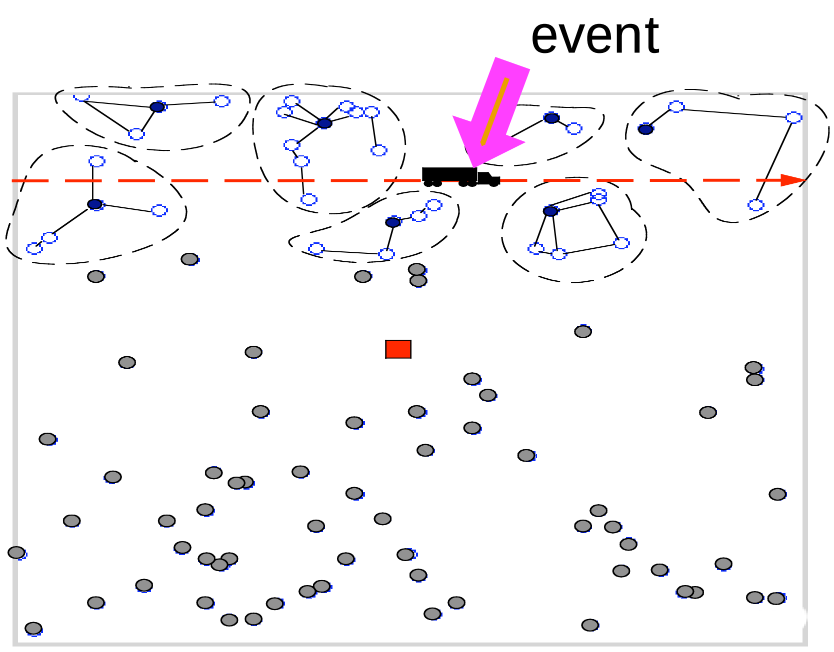
- Reactive clustering driven by the events
- Uses power control technique to minimize the transmission power
- A localized clustering protocol that simple local node behavior achieves a desired global objective



(A) A predefined clustering



(B) Clustering after DRC

Message Format

AICIP RESEAR

TYPE (4 bits)	Power Level (4 bits)	Destination ID (2 bytes)	Source ID (2 bytes)	Cluster ID (2 bytes)	Energy (4 bytes)	Signal Energy (4 bytes)

- TYPE: the type of message which can be REQUEST, REPLY, JOIN, JOIN-FORWARD and END.
- Power Level: the transmission power the node currently uses.
- Destination ID: the destination node identification and we use all 1's as the broadcast address.
- Source ID: the address of current node.
- Cluster ID: the cluster head address of the cluster the current node belongs to and we use 0 if the node is unclustered.
- Energy: the remaining energy of the node.
- Signal Energy: the signal energy sensed by the current node emitted by the potential target.

Messages are exchanged only locally

Three Tables

- Neighbor table
  - Node ID
  - Energy
  - Signal energy
  - Power level
- Routing table
  - Cluster ID
  - Via
- Participation table (only cluster head has it)
  - Node ID
  - Via

Outline of DRC

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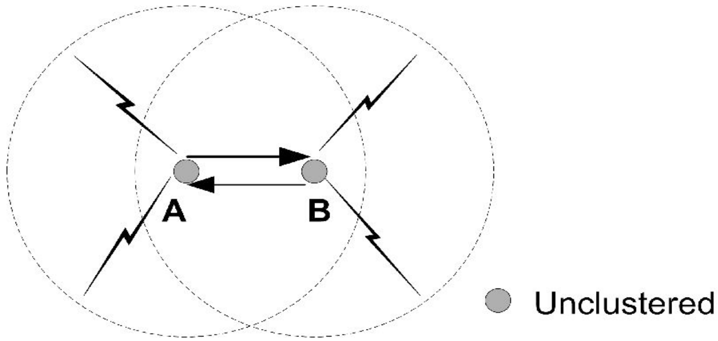
- Post-deployment Phase
  - Turn off radio, CPU into the "sleep" mode, only the sensor left functioning
- Cluster Forming Phase (start at the lowest level of transmission power)
  - Wait for a period of time T_x(e_x) ~ N(0, σ)
    - Can receive REQUEST, REPLY, JOIN msgs but cannot send msgs
  - Broadcast REQUEST and start another timer T_wait
  - Increase transmission power and rebroadcast
  - 4 scenarios in determining the cluster head
  - If at P_m, still no response, elect itself as the cluster head
- Intra-cluster data processing phase
  - After being elected, wait for a certain time, send CHANGE-PHASE to all mer
  - Nodes transmit their data to the cluster head
- Cluster head to processing center phase
  - Cluster heads increase transmission power
  - Send the partial results to the processing center

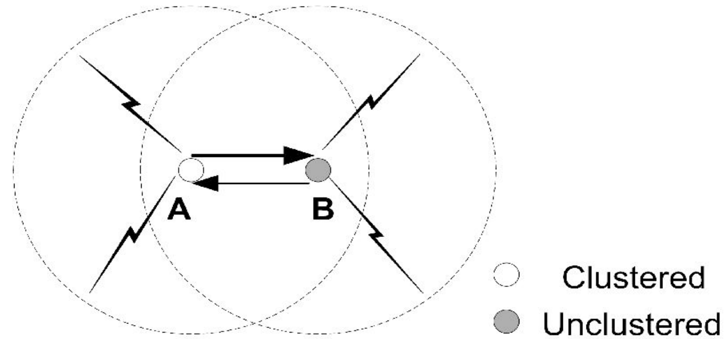
TYPE (4 bits)	Power Level (4 bits)	Destination ID (2 bytes)	Source ID (2 bytes)	Cluster ID (2 bytes)	Energy (4 bytes)	Signal Energy (4 bytes

Different Scenarios

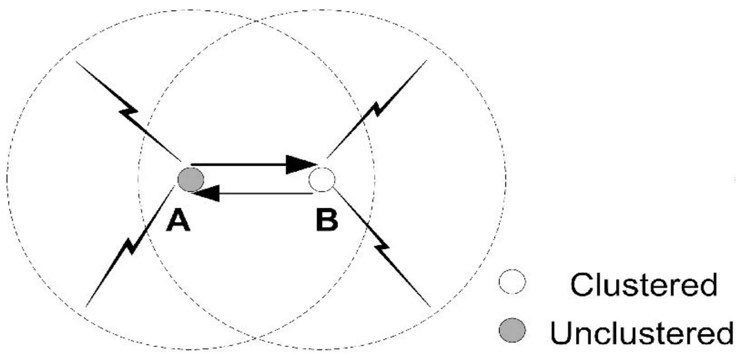
AICIP RESEAR



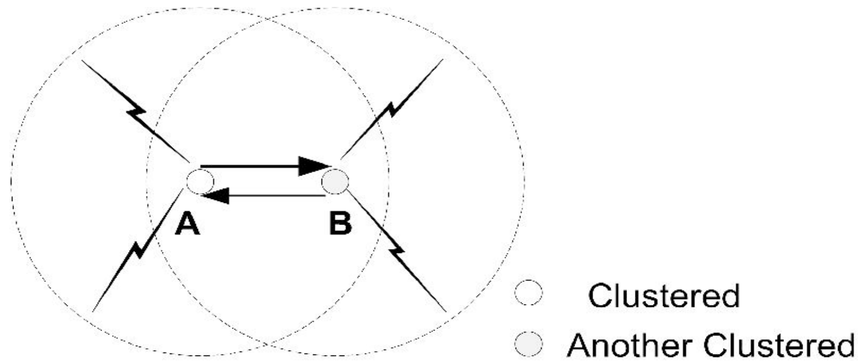
Node A, B unclustered
Choose one with higher energy as cluster head



Node A clustered, node B unclustered, sends out REPLY or JOIN that B overhe
B joins the cluster A belongs to



Node A unclustered, node B clustered
A joins the cluster B belongs to



Node A, B clustered
B discards the message

Performance Evaluation of DRC

- Develop a simulator in JAVA
- Implement LEACH protocol and a predefined fixed clustering protocol. Add the reactive feature to them.
- LEACH:
  - Heinzelman, 2000. (MIT)
  - Random rotation of cluster head
- Metrics:
  - Energy consumption
  - Network lifetime

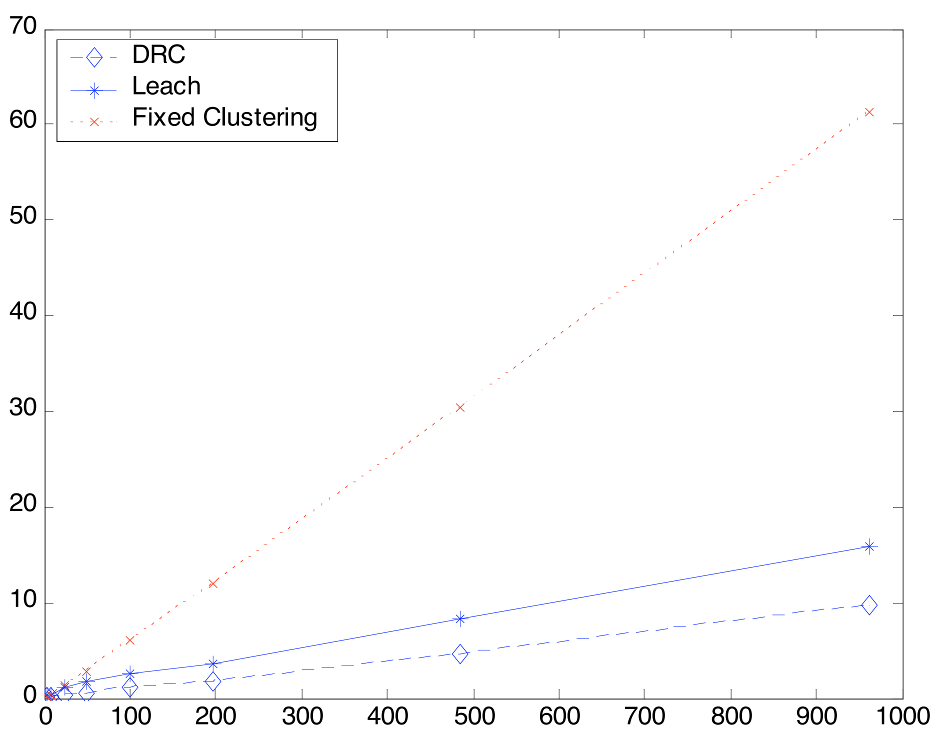
Parameters in Simulation

AICIP RESEAR

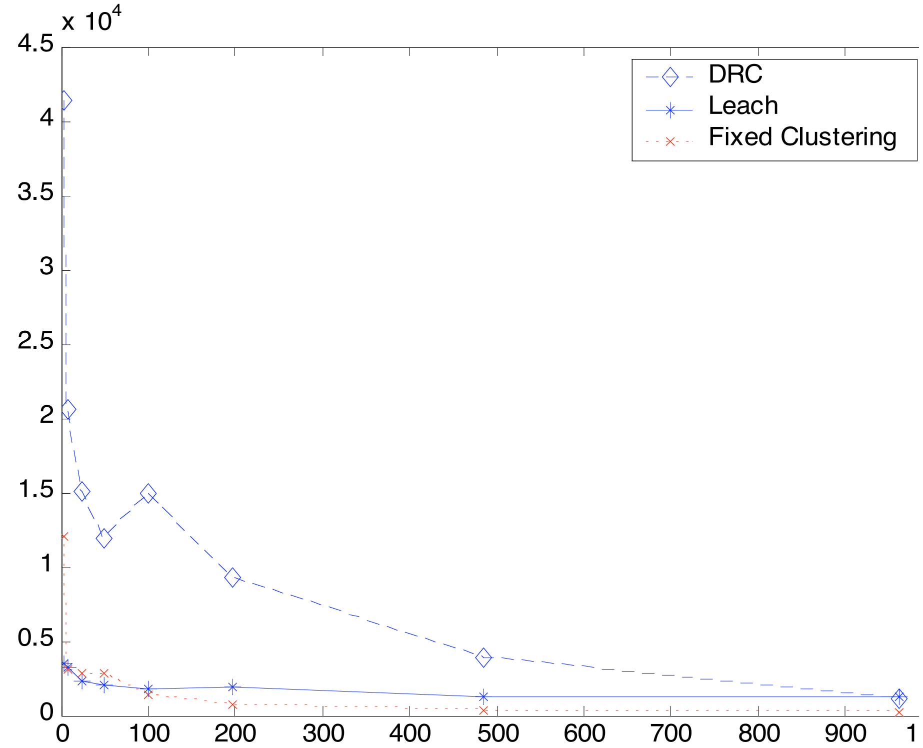
- Node number: 100
- Sensing range: 20m
- Target speed: 20m/s
- Event number: 3

- 30m by 30m area
- Transmit power level: 8
- Initial energy: 36 joules
- Message size: 152 bits
- Simulation time: 20s
- Transmit power: 0.2355-52.981mW
- Receive power: 10.50mW
- Idle power: 10.36mW
- Sleep power: 1.0mW

Number of Nodes

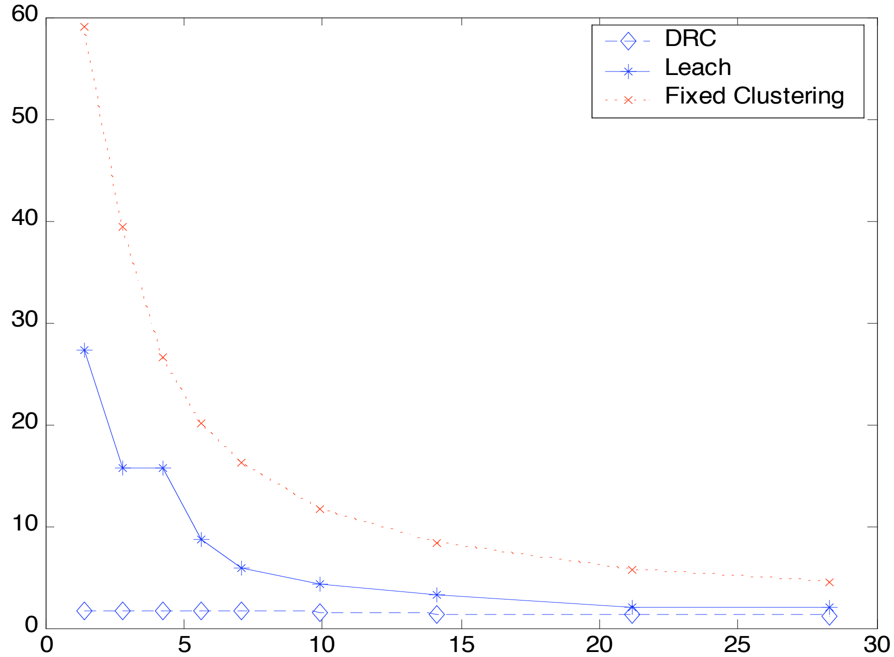


(A) Energy Consumption

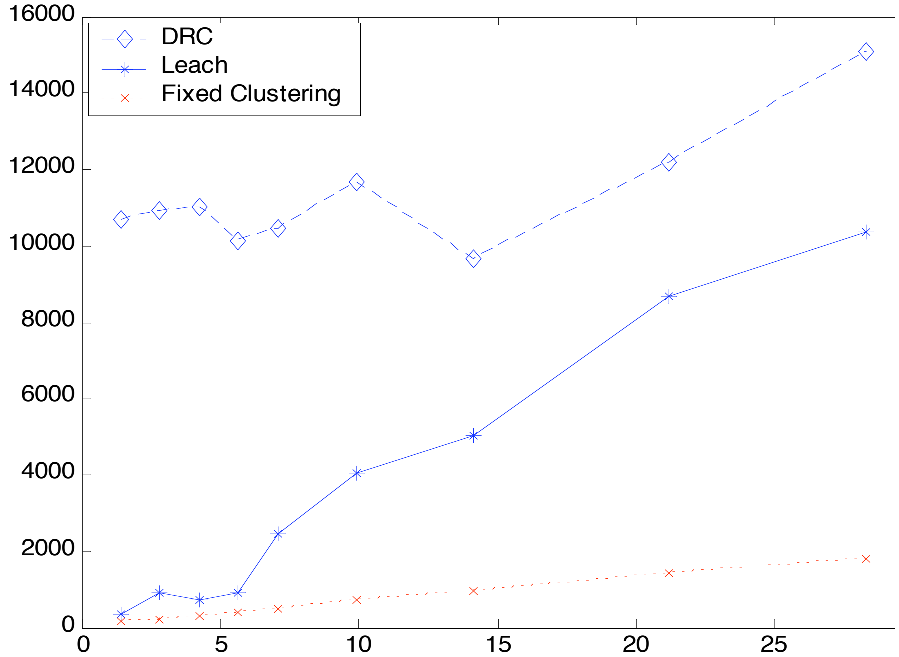


(B) Network Lifetime

Target Speed

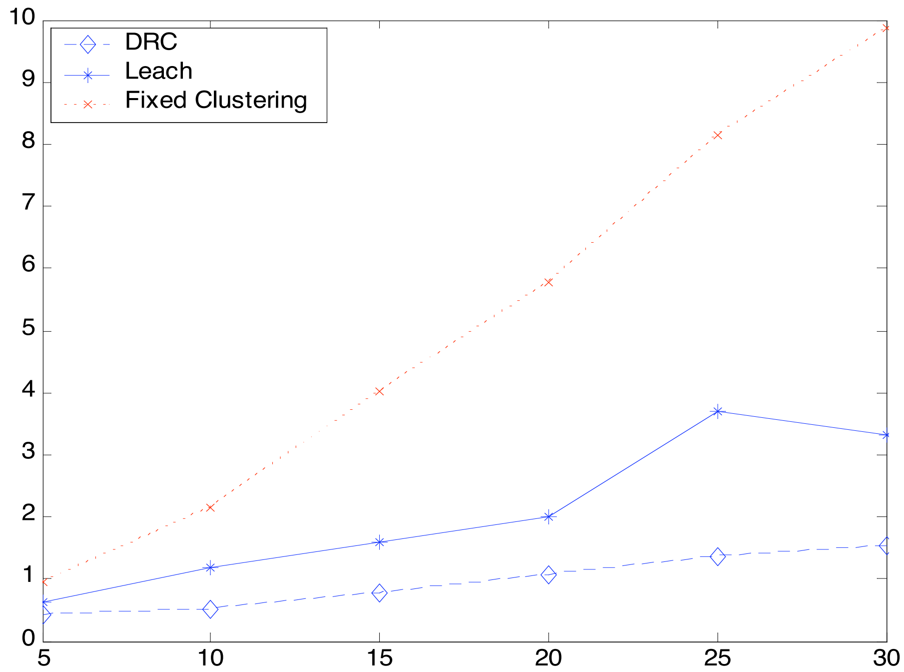


(A) Energy Consumption

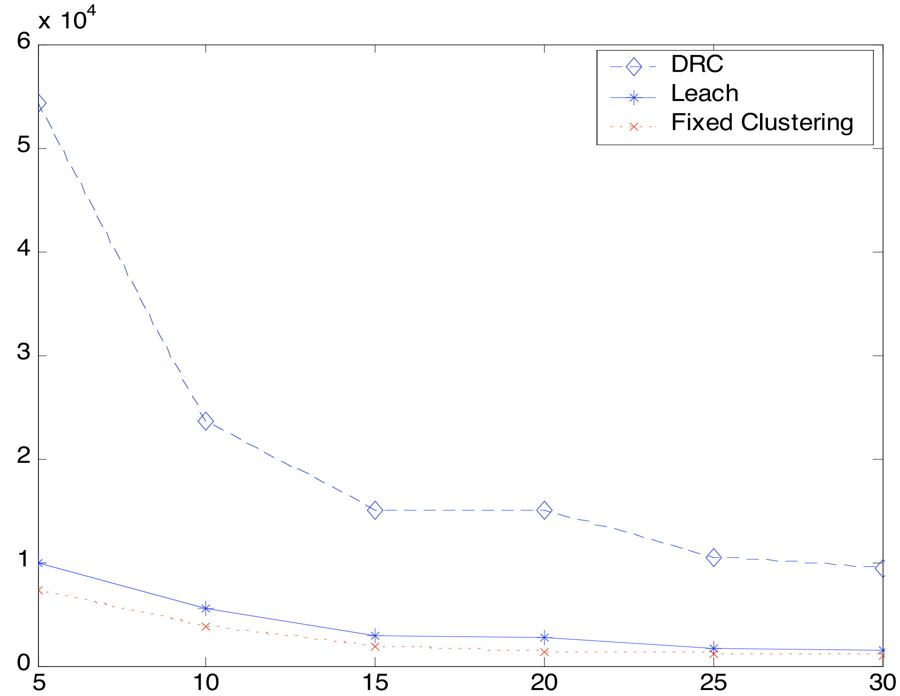


(B) Network Lifetime

Signal Range

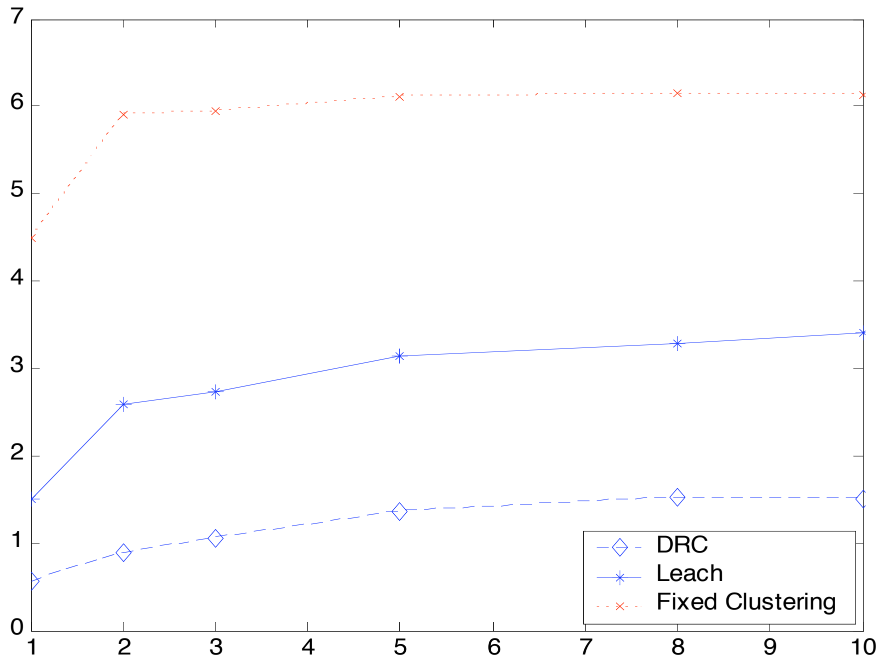


(A) Energy Consumption

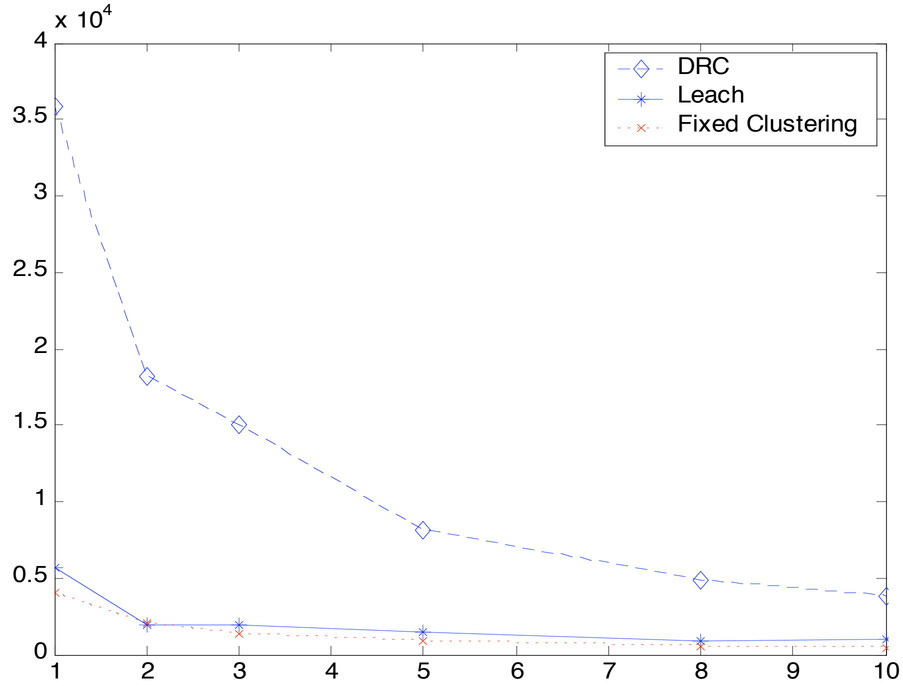


(B) Network Lifetime

Number of Events



(A) Energy Consumption



(B) Network Lifetime

Conclusions

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- 3 desirable features:
  - Reactive
  - Power Control Technique
  - Localized Protocol
- Simulation results show great improvements in energy efficiency and network lifetime

Sensor Selection

Design Objectives

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- Select a representative subset of sensors for detection
- Achieve coverage of entire region by electing sensors from all corners of network
- Achieve fault-tolerance by retaining some level of redundancy
- Ensure limited overhead
  - Low latency, limited energy consumption and simplicity

Modeling Assumptions

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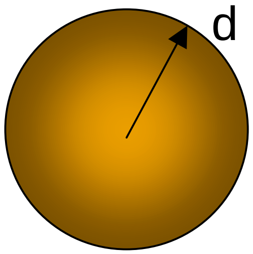
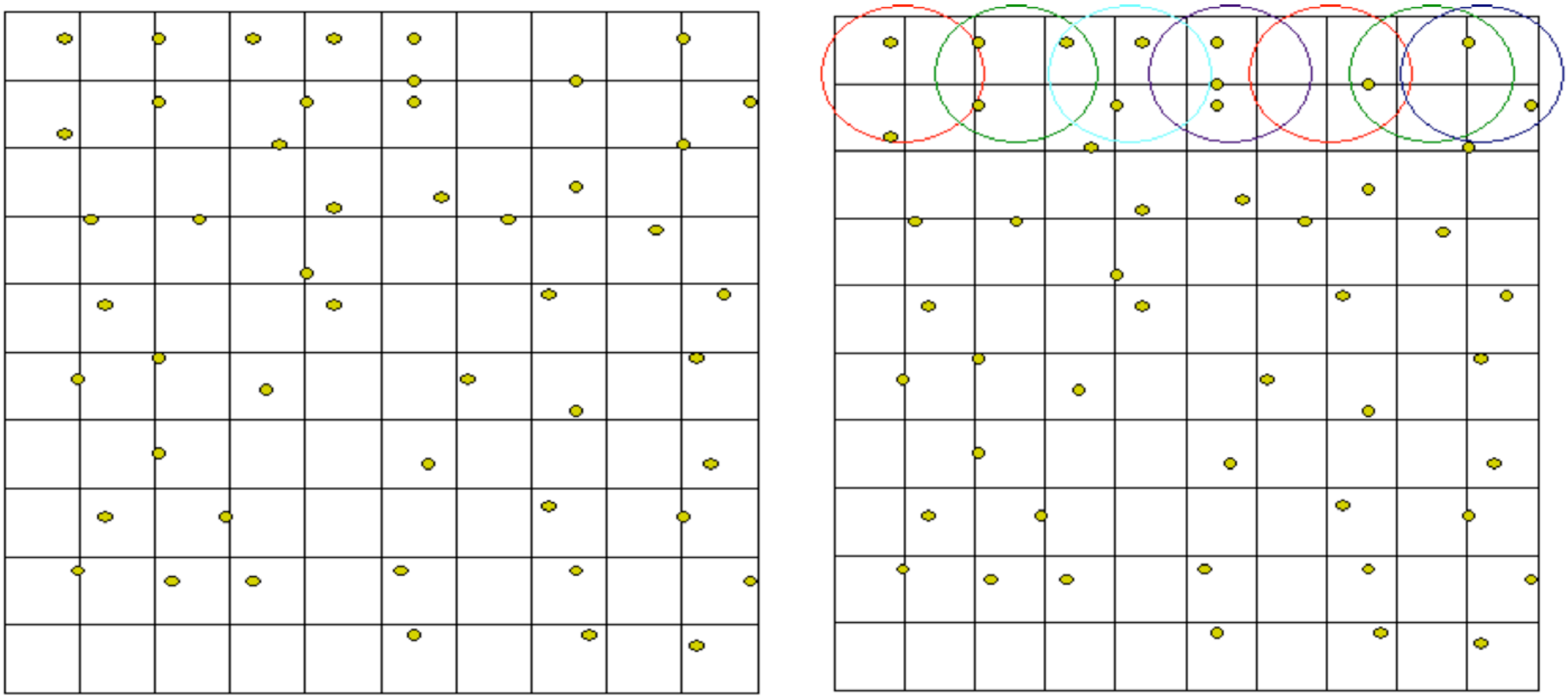
- Target can be modeled as an isotropic radiating source generating a spatial signal with power law decay

$$E_{received} = \frac{E_{source}}{d^{\alpha}} \qquad \alpha = 2$$



  – Acoustic signals fall in this category
- Nodes are capable of power control

Systematic Sampling



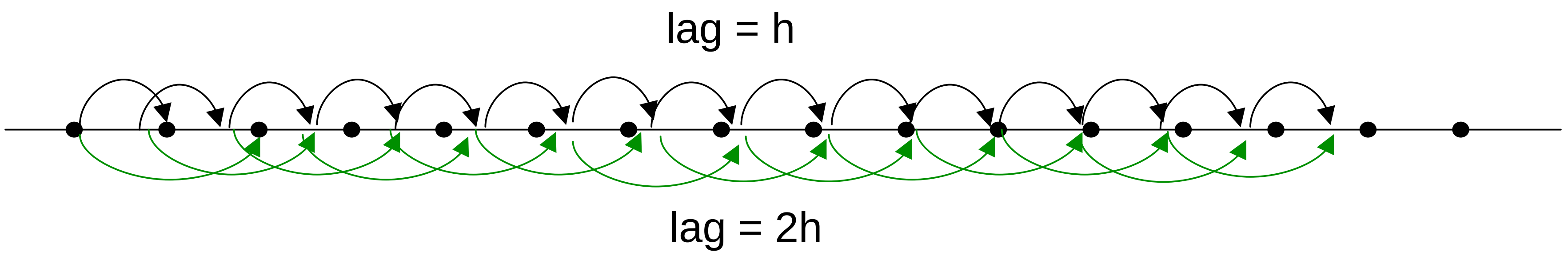
- Sample the sensor field systematically using overlapping discs of fixed radius
  - Virtual grid requires node location information
- Exploit spatial dependence to select sensors autonomously

Estimating Spatial Dependence

- The Semi-variogram is the major tool in geo-statistics used for estimating spatial dependence

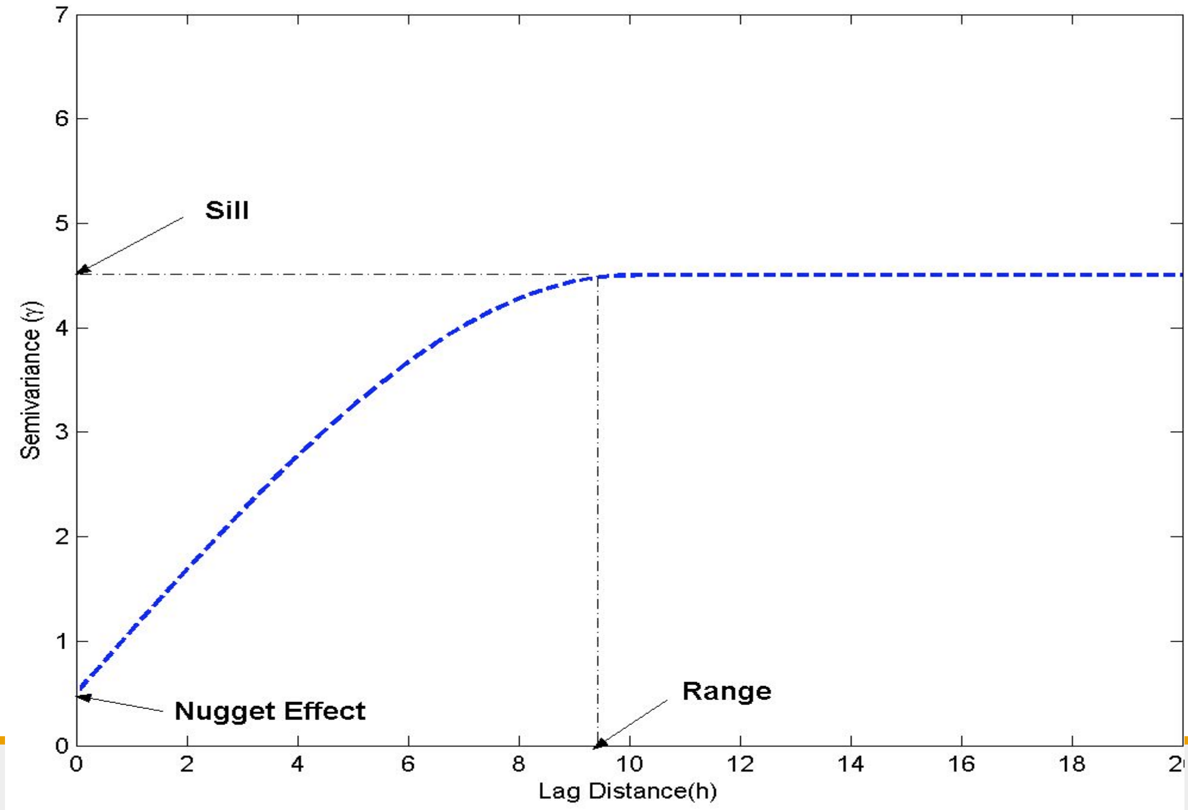
$$\hat{\gamma}(\mathbf{h}) \equiv \frac{1}{2|N(\mathbf{h})|}\sum_{N(\mathbf{h})}(Z(\mathbf{s}_i) - Z(\mathbf{s}_j))^2,$$

$\gamma(\mathbf{h})$ is the semi-variance at lag $\mathbf{h}$, i.e., distance between locations s_i and s_j. $Z(\mathbf{s}_i), Z(\mathbf{s}_j)$ are the values of variable Z at locations s_i, s_j. $|N(\mathbf{h})|$ is the number of pairs of observed data points separated by lag h.

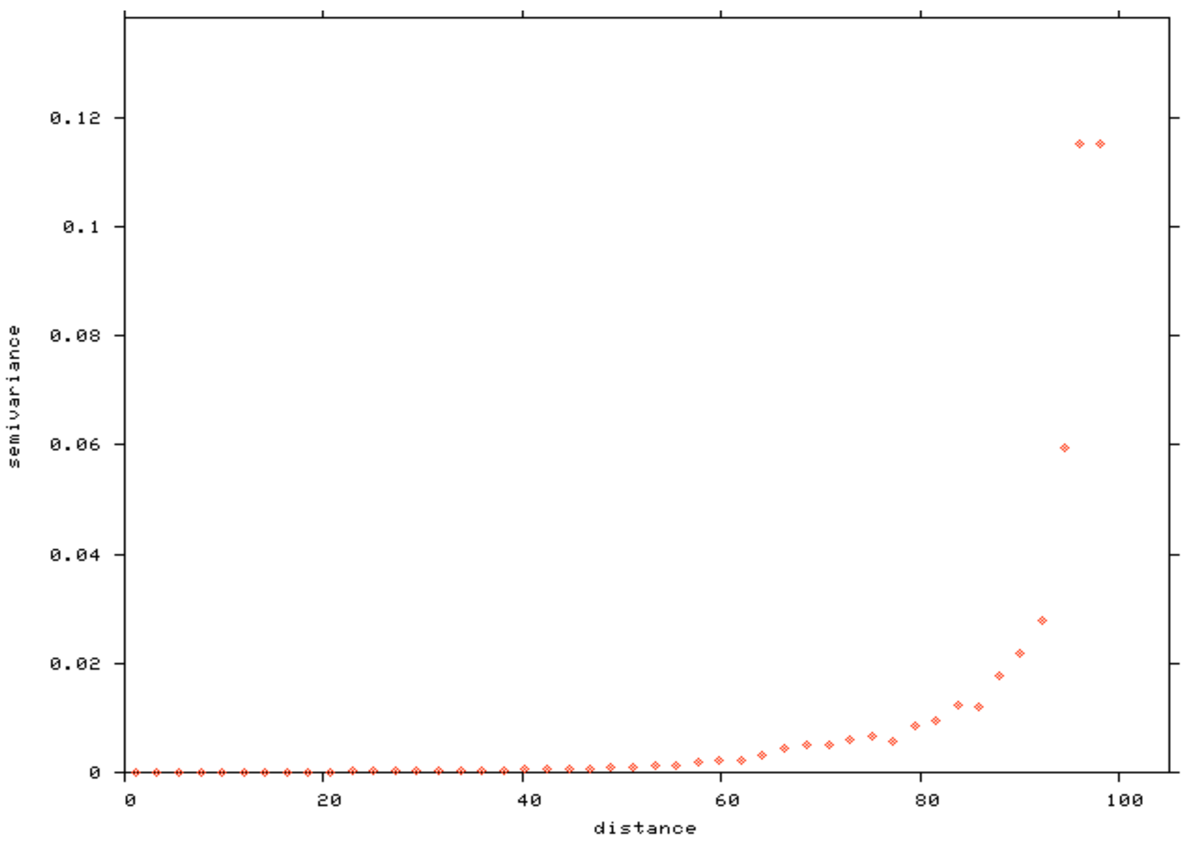


The Semi-variogram

- At distance called the Range, the data measurements cease to be strongly correlated.
- Theoretical models used for fitting practical semi-variograms include Power-law, exponential, Gaussian, spherical etc.

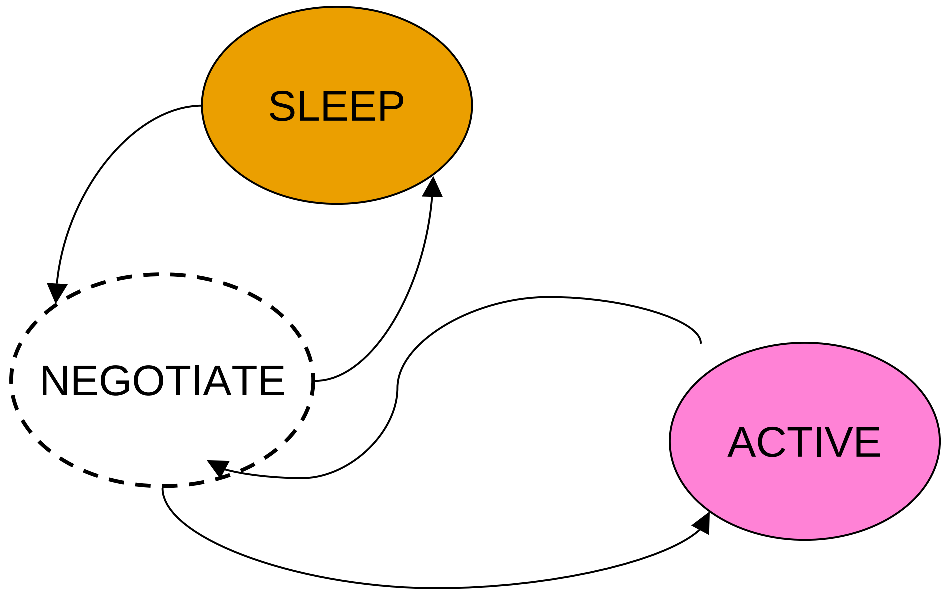


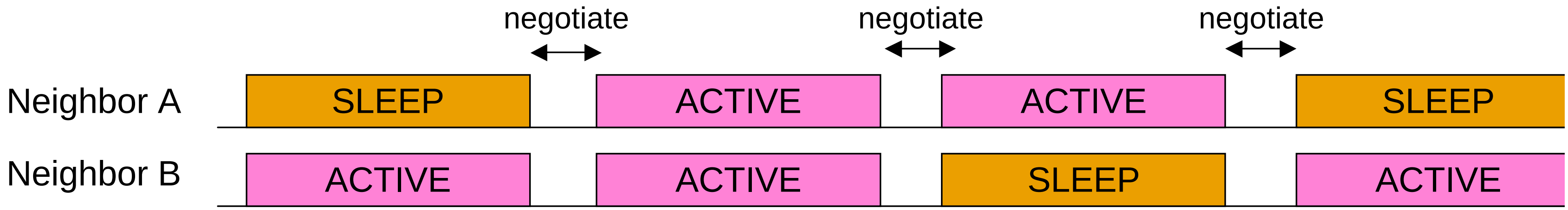
The Semi-variogram



- Resulting power law semi- variogram implies infinite correlation distance (range)
- Solution:
  - Select Range R such that
    - R < sensing range and
    - R < transmission range
- R will be used as a selection parameter

State Machine





Spatial Selection - Pseudo-Code

Pre-deployment Phase

```
begin
  r_negotiate ← constant
  t_sleep ← constant
```

Post-deployment Phase

```
  for each Node n_i do
    n_i.state = NEGOTIATE
    set transmitPower ∝ r_negotiate
    energyPacket.send()
  end
  for each Node n_j neighbor of Node n_i do
    energyPacket.receive()
    if Node n_j.energy ≤ Node n_i.energy then
      n_j.state = SLEEP
    else
      n_j.state = ACTIVE
    end
  end
end
```

Simulation Environment

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- Developed a simulator in JAVA using 3 classes
  - Node, Message, Main classes
  - Main class implements interactions between Node and Message
- Simulation carried out include
  - Energy consumption with $r_{negotiate}$, t_{sleep}, network density
  - Spatiality of selected subsets
  - Worst case energy consumption for one round of algorithm
    - with varying $r_{negotiate}$, density
  - Coverage redundancy
  - Uniformity of coverage
  - Fault tolerance

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Simulation Parameters

Component	Energy Dissipated
Transmitter/Receiver Electronics	50nJ/bit
Transmit Amplifier	100pJ/bit/m^2

Parameter	Value
Transmission Rate	16 Kbps (CBR)
Number of Nodes	200 (initial)
Network Area	50m by 50m
Topology	Random (uniform distribution)
Initial Node Energy	35-36 Joule random
Sensing Radius	12 m

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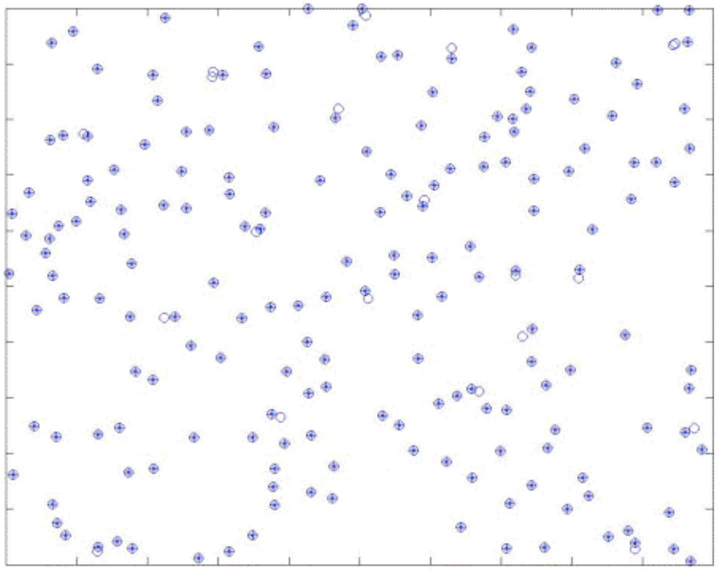
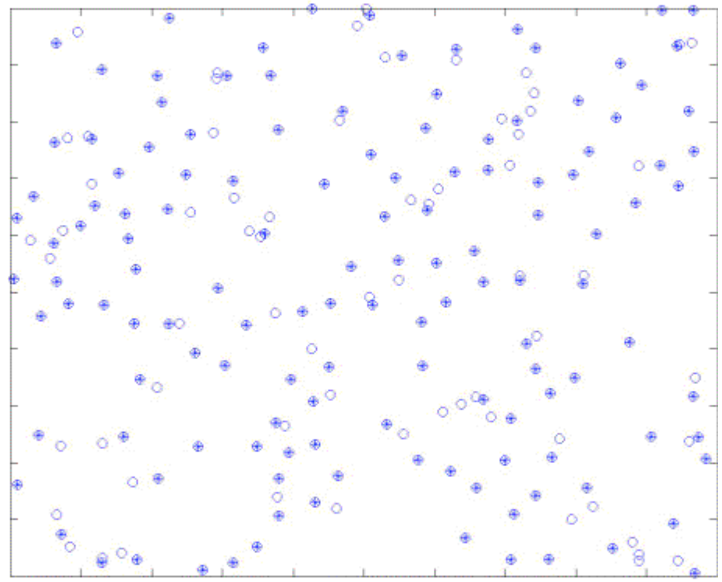
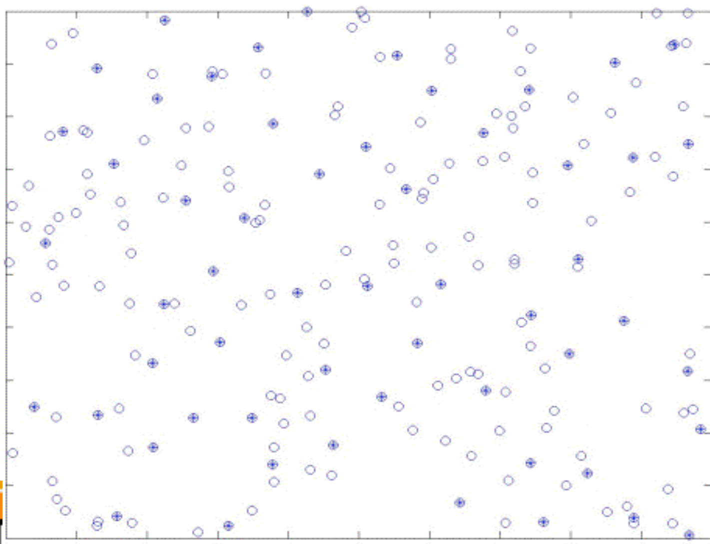
Effect of Variation in Range



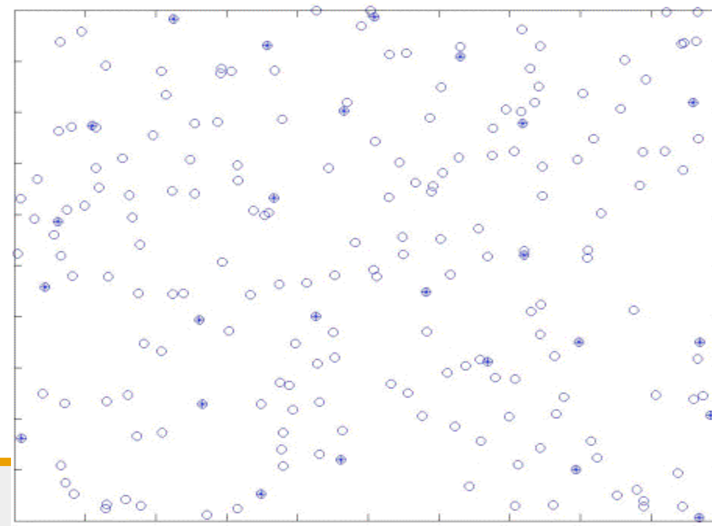
r=1,
N = 174



r=2,
N=129

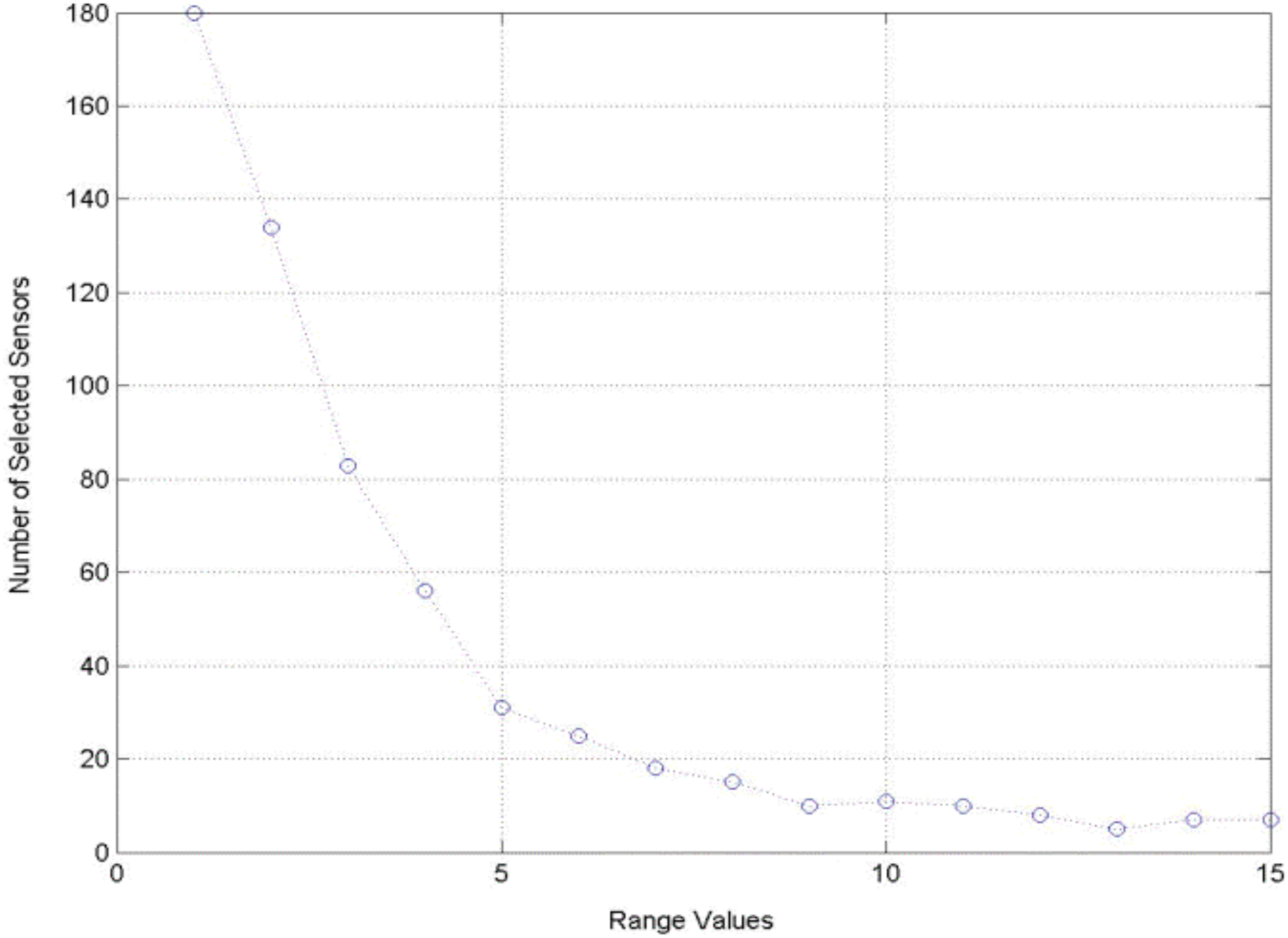


r=4,
N=58

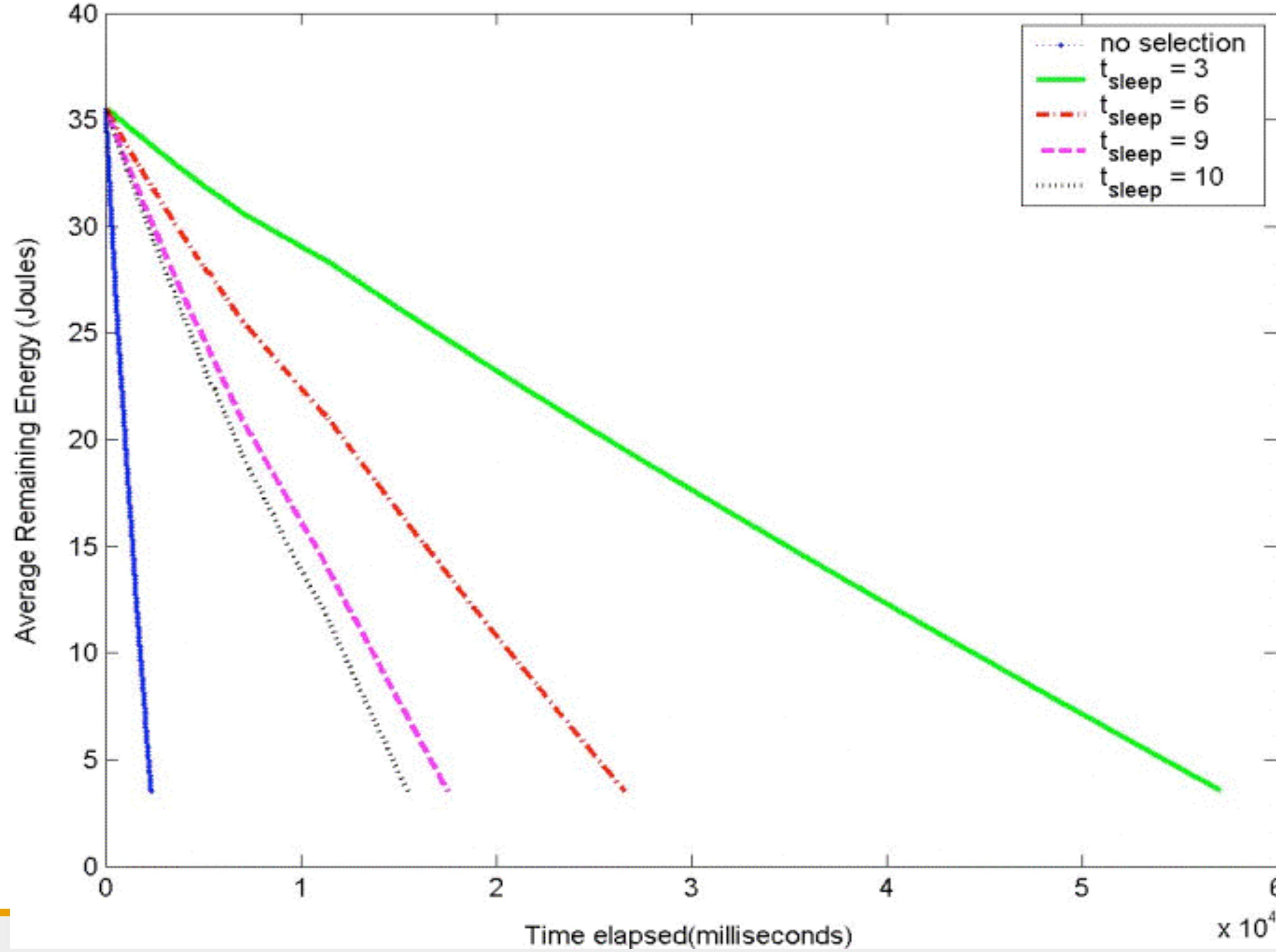


r=6,
N=25

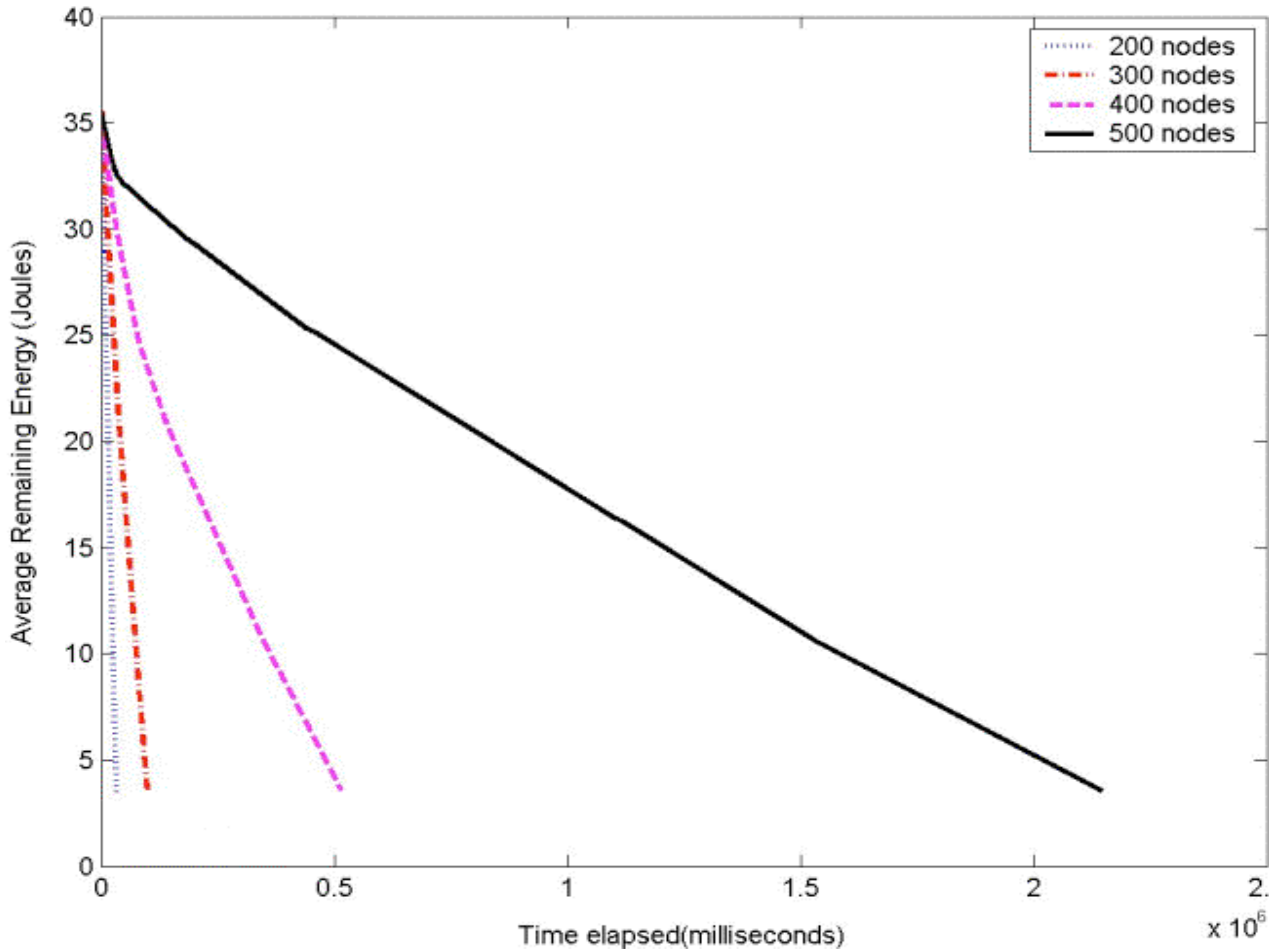
Selected Sensors against Range Values



Energy Consumption with t_{sleep} ($r_{negotiate}$ = 3m)



Energy Consumption with Density ($r_{negotiate}$ = 3m)



Sensing Redundancy

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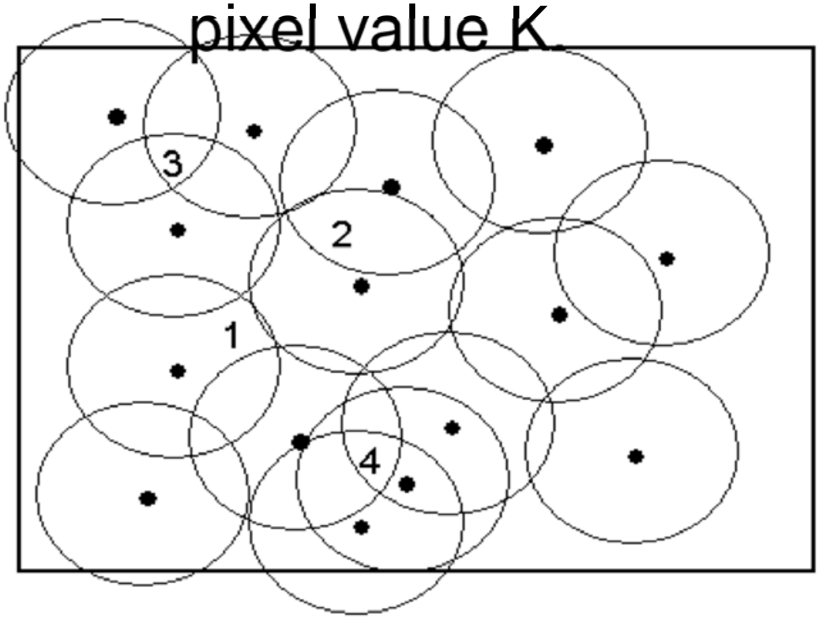
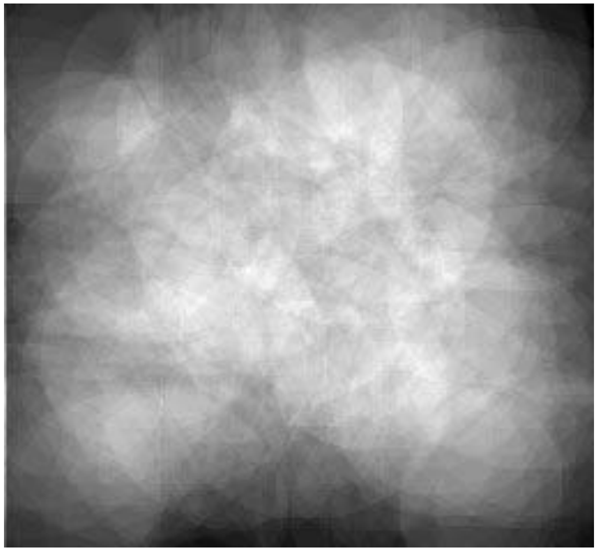
- Represent the sensing field by a coverage map
  - For each sensor covering point in the coverage map increment the pixel value by 1.
  - A point covered by K-sensors has K-coverage and pixel value K.



Coverage map construction



Original network coverage map (200 nodes)

Sensing Redundancy

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- Consider an application that requires 1-coverage
- Defined using three parameters
  - Absolute Redundancy (A.R.)
    - Count of the number of points covered above a required threshold (e.g. 1- coverage)
  - Relative Redundancy (R.R.)
    - Divide absolute redundancy by size of image
    - Reflects percentage of square region that is covered
  - Coverage Contiguity (C.C.)
    - Determines if covered region is contiguous
- Image size (256 x 256), sensing radius – 12m
- Original Network – A.R. = 65536, R.R.=1, C.C. = Yes

Sensing Redundancy

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$r_{negotiate}$	A. R.	R. R.	C.C.
1	65536	1	Yes
2	65536	1	Yes
3	65536	1	Yes
4	65535	0.9999	Yes
5	64245	0.9803	Yes
6	62038	0.9466	Yes
7	52799	0.8056	Yes
8	48028	0.7328	No
9	26575	0.4055	No
10	41355	0.6310	Yes
11	27873	0.4253	No
12	16268	0.2482	No
13	2842	0.0434	No
14	7836	0.1196	No
15	13348	0.2037	No

A.R. – Absolute Redundancy, R.R. – Relative Redundancy, C.C.-Coverage Contiguity

Coverage Uniformity

AICIP RESEAR

- To characterize uniformity of coverage
  - Mean of coverage values

$$\mu = \frac{1}{N}\sum_{i=1}^{N} p_i$$

  - Variance of coverage values

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N} (p_i - \mu)^2$$

  - Spatial uniformity (S.U.)

$$S.U. = \frac{\sum_{i=1}^{N} (p_i * [x, y])}{\sum_{i=1}^{N} p_i}$$

where p_i is the *i*-th pixel value, [x,y] is the coordinate vector of the pixel and *N* is the total number of pixels

Fault Tolerance – Redundancy

AICIP RESEAR

% Faulty Nodes	A. R.	R. R.	Coverage
5	65536	1	Yes
10	65536	1	Yes
15	65451	0.9987	Yes
20	65536	1	Yes
25	65450	0.9987	Yes
30	65450	0.9987	Yes
35	65450	0.9987	Yes
40	65170	0.9944	Yes
45	64981	0.9915	Yes
50	63830	0.9739	Yes

- 200 Nodes deployed, $r_{negotiate}$ = 3m
- Level at which coverage is lost will depend on the chosen value of $r_{negotiate}$ and the density of the network
- Results shown are for 1-Coverage
- At 50% node failure, 97% redundancy is achieved but coverage is achieved.

Summary

- Application of geo-statistical techniques in sensor networks
  - Exploiting redundancy by estimating spatial dependence
  - Framework for determining the correlation distance of a sensor network
- Spatial node selection algorithm that is potentially more energy-efficient than similar protocols
- Extensive evaluation of the proposed algorithm
- Simulator environment for assessment of selection protocol

Reference

AICIP RESEAR

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