An Energy Efficient Hierarchical Clustering Algorithm for Wireless Sensor Networks

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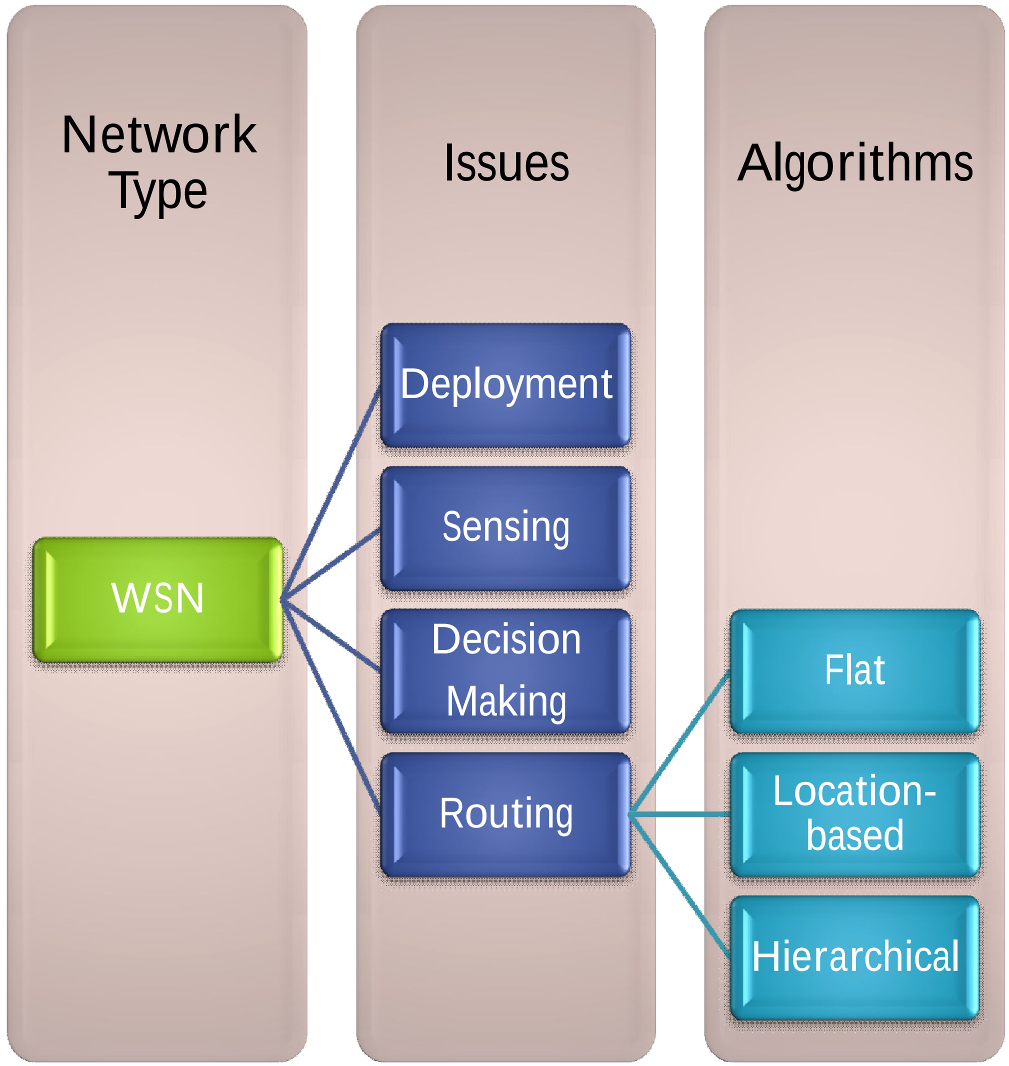
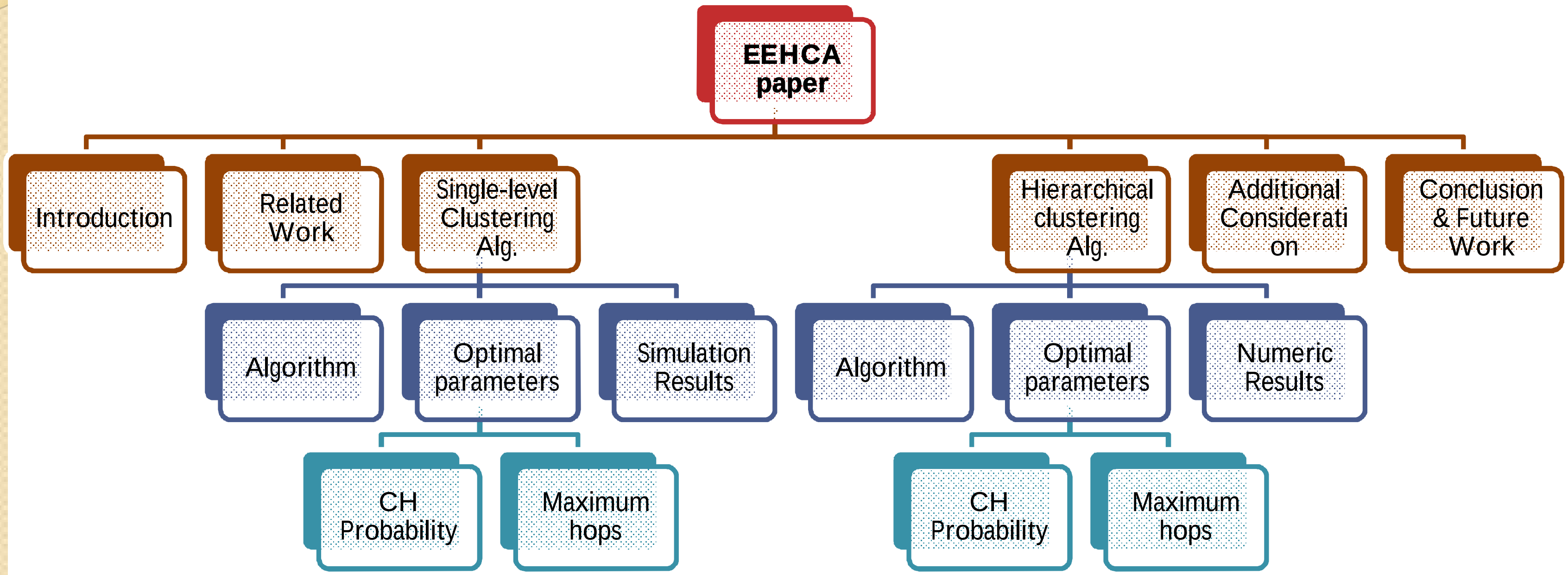
About the paper

- Appeared in INFOCOM 2003
- 11 pages
- 30 references
- Cited by 673 papers

Topic classification



Paper Structure



Related Work

- LCA
- LCA2
- WCA
- DCA
- DMAC
- LEACH
- non-purely hierarchical models

Assumptions (1/2)

a) The sensors are distributed as per a homogeneous spatial Poisson process of intensity λ in 2-D space.

b) All sensors transmit at the same power level so have the same radio ranger.

c) Data exchanged between two communicating sensors not within each others' radio range is forwarded by other sensors.

Assumptions (2/2)

d) A distance of ***d*** between any sensor and its cluster head is equivalent to ***d / r*** hops.

e) Each sensor uses one unit of energy to transmit or receive one unit of data.

f) A routing infrastructure is in place;

so, only the sensors on the routing path forward the data.

g) The communication environment is contention- and error-free. (No retransmit)

Single-level Clustering Algorithm

1. Each sensor becomes a cluster-head (CH) with probability ***p*** and advertises itself as a CH to the sensors within its radio range.
2. The advertisement is forwarded to all the sensors that are no more than ***k*** hops away from CH. Any sensor that receives such advertisements and is not itself a CH joins the cluster of the closest CH.
3. Any sensor that is neither a CH nor has joined any cluster itself becomes a CH.

Optimal parameters

Probability of becoming a Clusterhead

$$p = \left[\frac{1}{3c} + \frac{\sqrt[3]{2}}{3c\left(2 + 27c^2 + 3\sqrt{3}c\sqrt{27c^2 + 4}\right)^{1/3}} + \frac{\left(2 + 27c^2 + 3\sqrt{3}c\sqrt{27c^2 + 4}\right)^{1/3}}{3c} \cdot \frac{1}{\sqrt[3]{2}} \right]^2$$

where $c = 3.06a\sqrt{\lambda}$.

Maximum number of hops allowed from a sensor to its clusterhead

$$k_1 = \left\lceil \frac{1}{r}\sqrt{\frac{-0.917\ln(\alpha/7)}{p_1\lambda}} \right\rceil.$$

Results (1/4)

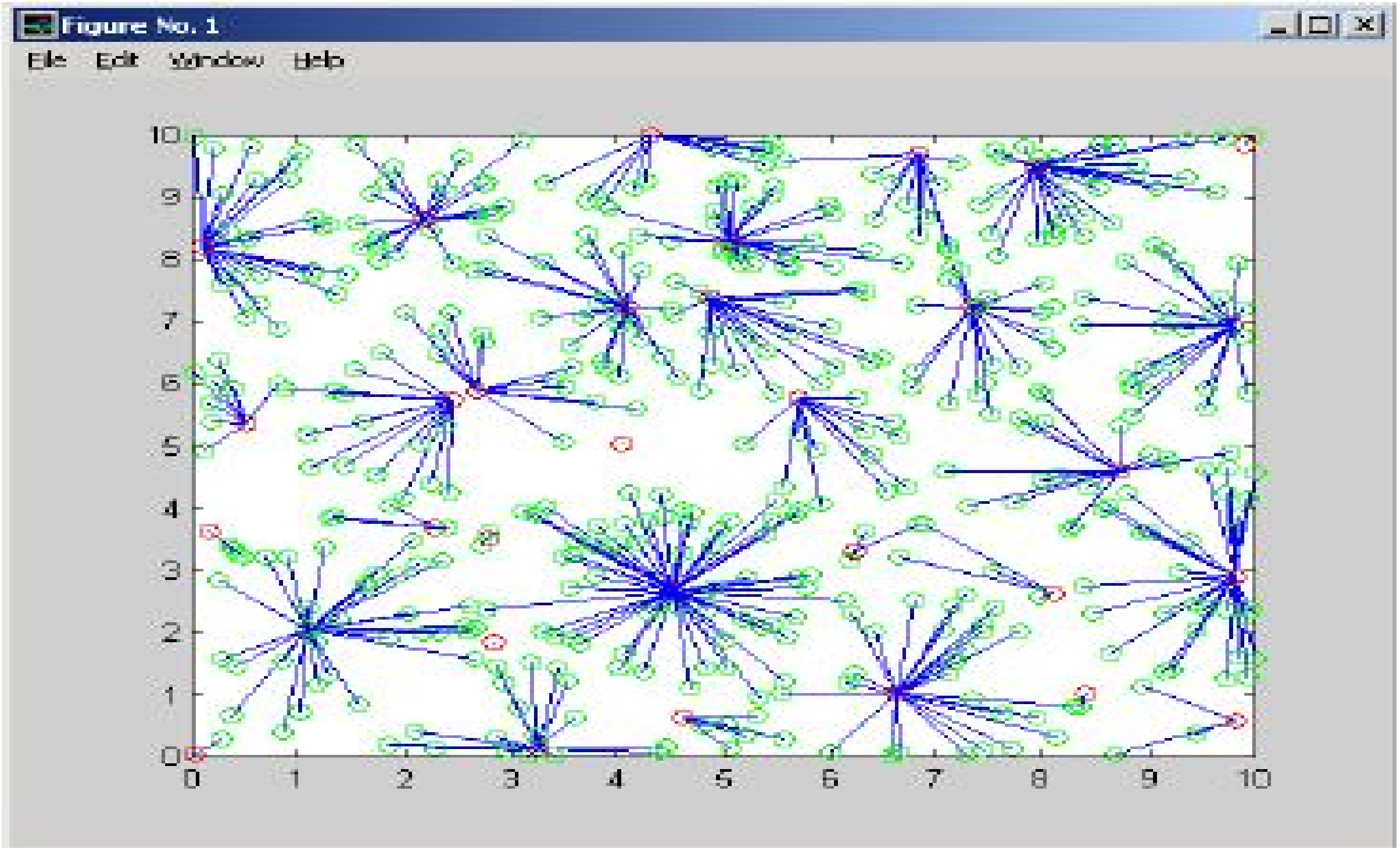
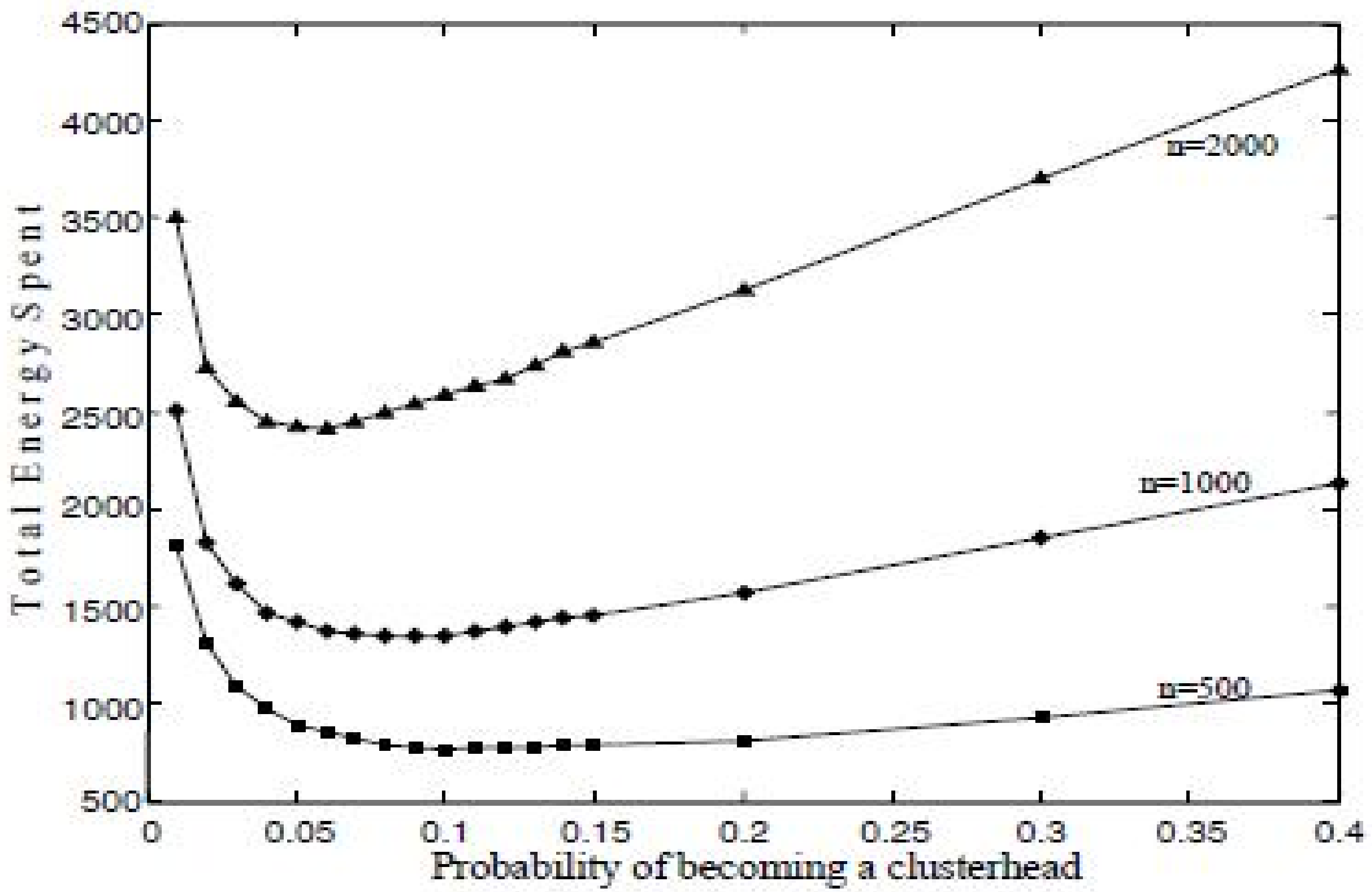


Figure No. 1
File Edit Window Help
10
9
8
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10

Results (2/4)



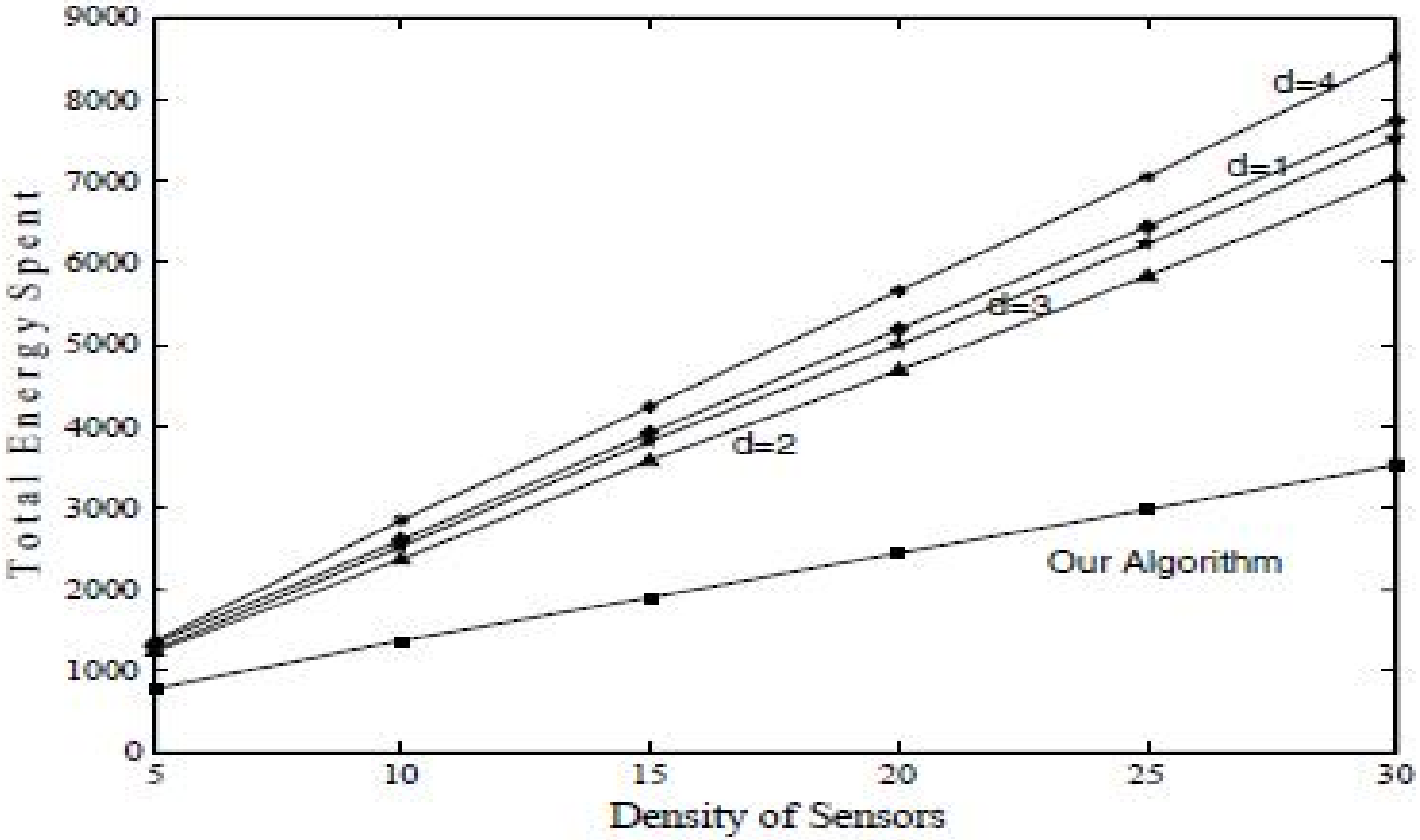
Total Energy Spent
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Probability of becoming a clusterhead
n=2000
n=1000
n=500

Results (3/4)

TABLE I. ENERGY MINIMIZING PARAMETERS FOR THE ALGORITHM

Number of Sensors (n)	Density (d)	Probability (p_{opt})	Maximum Number of Hops (k)
500	5	0.1012	5
1000	10	0.0792	4
1500	15	0.0688	3
2000	20	0.0622	3
2500	25	0.0576	3
3000	30	0.0541	3

Results (4/4)



Total Energy Spent
Density of Sensors
d=4
d=1
d=3
d=2
Our Algorithm
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
5
10
15
20
25
30

Hierarchical Clustering Alg. (1/2)

- Each sensor decides to become a level-1 CH with p_1 and advertises itself as a CH to the sensors within its radio range.
- This advertisement is forwarded to all the sensors within k_1 hops of the advertising. Each sensor that receives an advertisement joins the cluster of the closest level-1 CH; the remaining sensors become forced level-1 CHs.

Hierarchical Clustering Alg. (2/2)

- Level-1 CHs then elect themselves as level-2 CHs with a certain probability p_2 and broadcast their decision of becoming a level-2 CH. This decision is forwarded to all the sensors within k_2 hops.
- The level-1 CHs that receive the advertisements from level-2 CHs joins the cluster of the closest level-2 CH. All other level-1 CHs become forced level-2 CHs.
- CH at level *3,4,…,**h*** are chosen in similar fashion, with probabilities p_3, p_4,…, p_h respectively

Optimal parameters

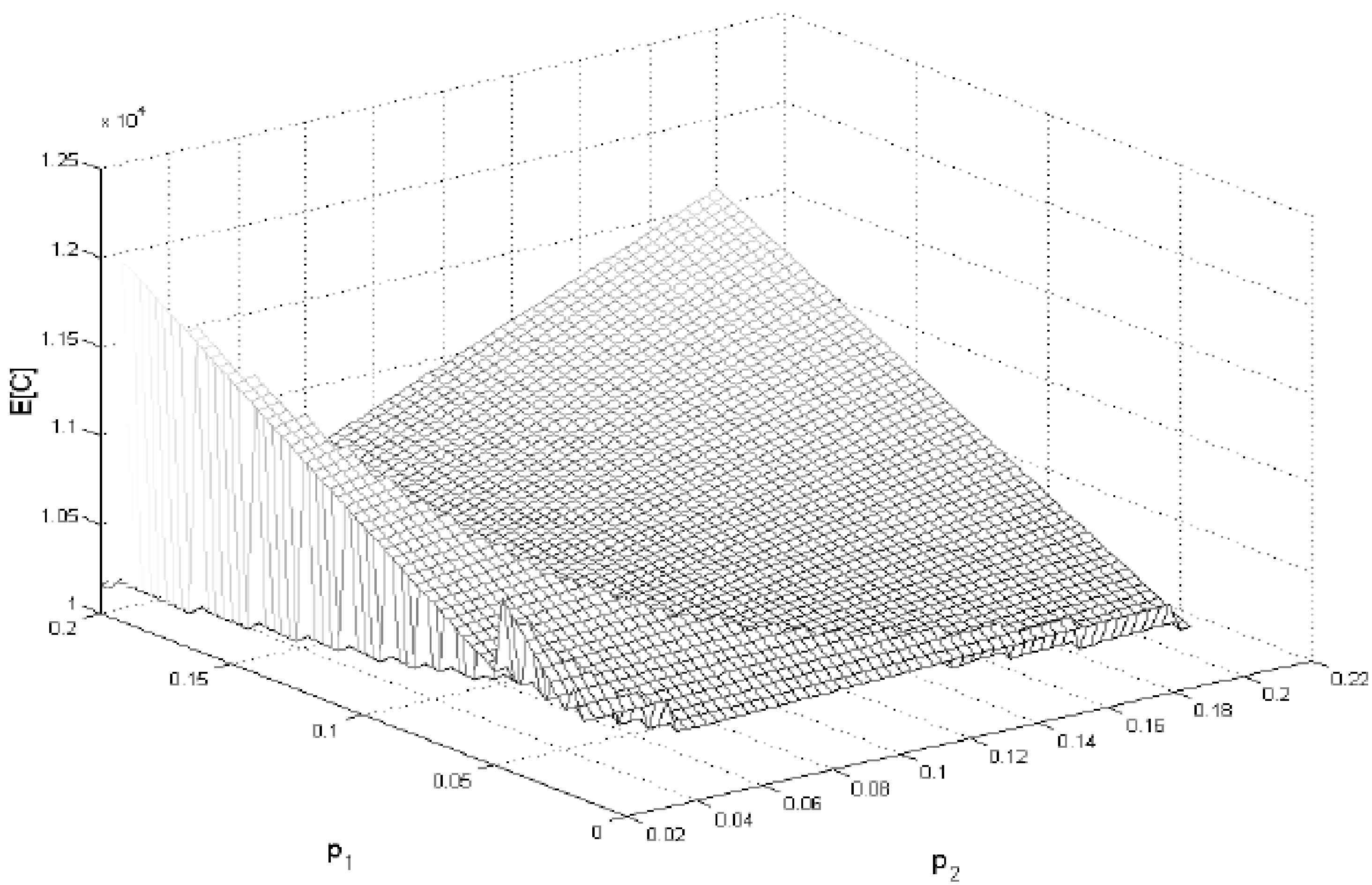
Probability of becoming a Clusterhead

$$E[C] = E[E[C \mid N = n]]$$
$$= \lambda A \prod_{i=1}^{h} p_i \left\lceil \frac{0.765a}{r} \right\rceil$$
$$+ \lambda A \sum_{i=1}^{h} (1 - p_i) \prod_{j=1}^{i-1} (p_j) \left\lceil \frac{1}{2r\sqrt{\lambda \prod_{j=1}^{i} p_j}} \right\rceil .$$

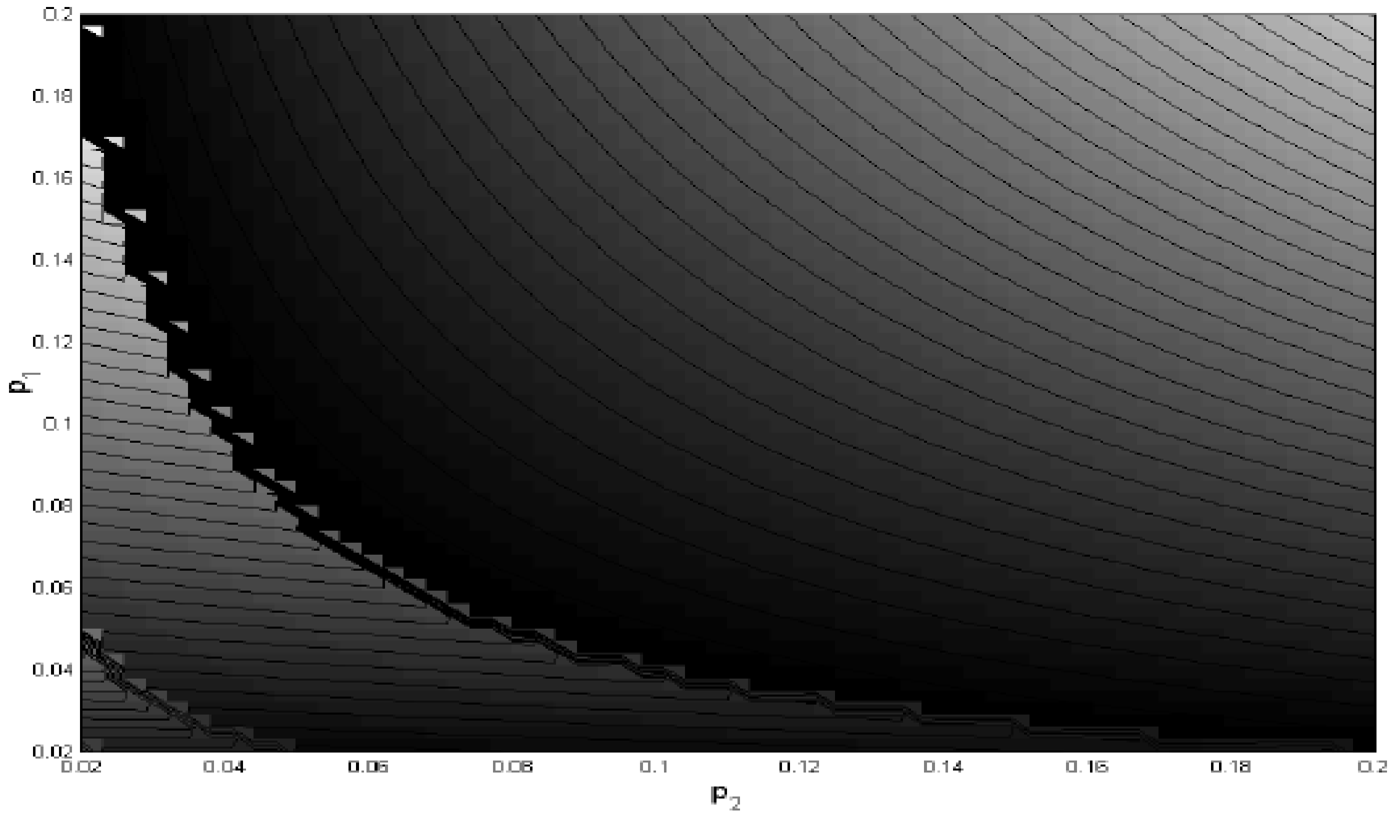
Maximum number of hops allowed from a sensor to its clusterhead

$$k_i = \left\lceil \frac{1}{r} \sqrt{\frac{-0.917 \ln(\alpha / 7)}{\lambda \prod_{j=1}^{i} p_j}} \right\rceil .$$

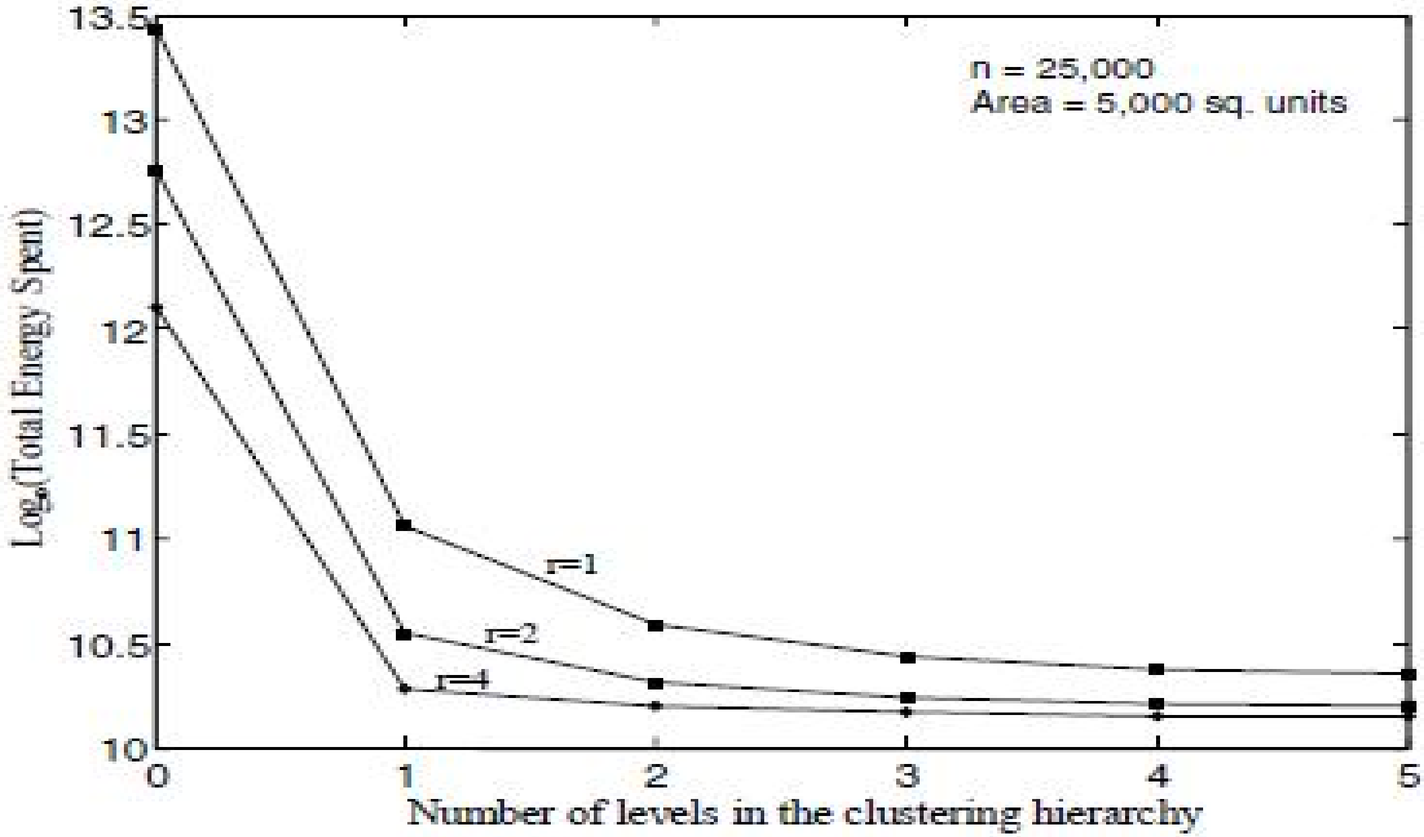
Results (1/4)


x 10^4
1.25
1.2
1.15
1.1
1.05
1
E[C]
0.2
0.15
0.1
0.05
0
p1
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
p2

Results (2/4)

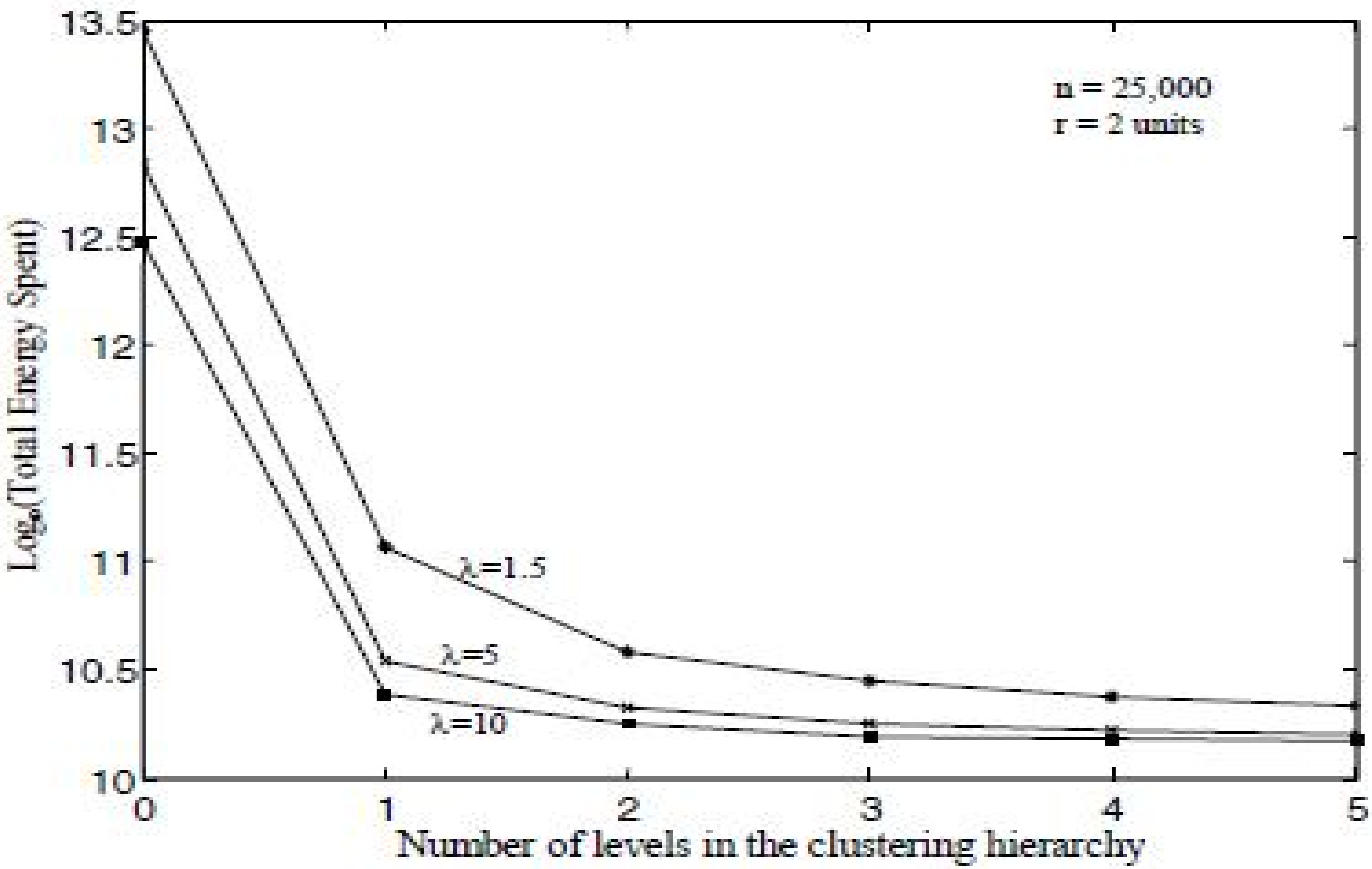

0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
p_1
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
P_2

Results (3/4)



n = 25,000
Area = 5,000 sq. units
Log(Total Energy Spent)
13.5
13
12.5
12
11.5
11
10.5
10
r=1
r=2
r=4
0
1
2
3
4
5
Number of levels in the clustering hierarchy

Results (4/4)


n = 25,000
r = 2 units
λ=1.5
λ=5
λ=10
Log$_e$(Total Energy Spent)
Number of levels in the clustering hierarchy
13.5
13
12.5
12
11.5
11
10.5
10
0
1
2
3
4
5

Q&A

Conclusion (1/2)

- A distributed algorithm proposed for organizing sensors into a hierarchy of clusters.
- Objective is minimizing the total energy spent in the system to communicate the information gathered by these sensors to the information-processing center.
- The optimal parameter values found for these algorithms that minimize the energy spent in the network.

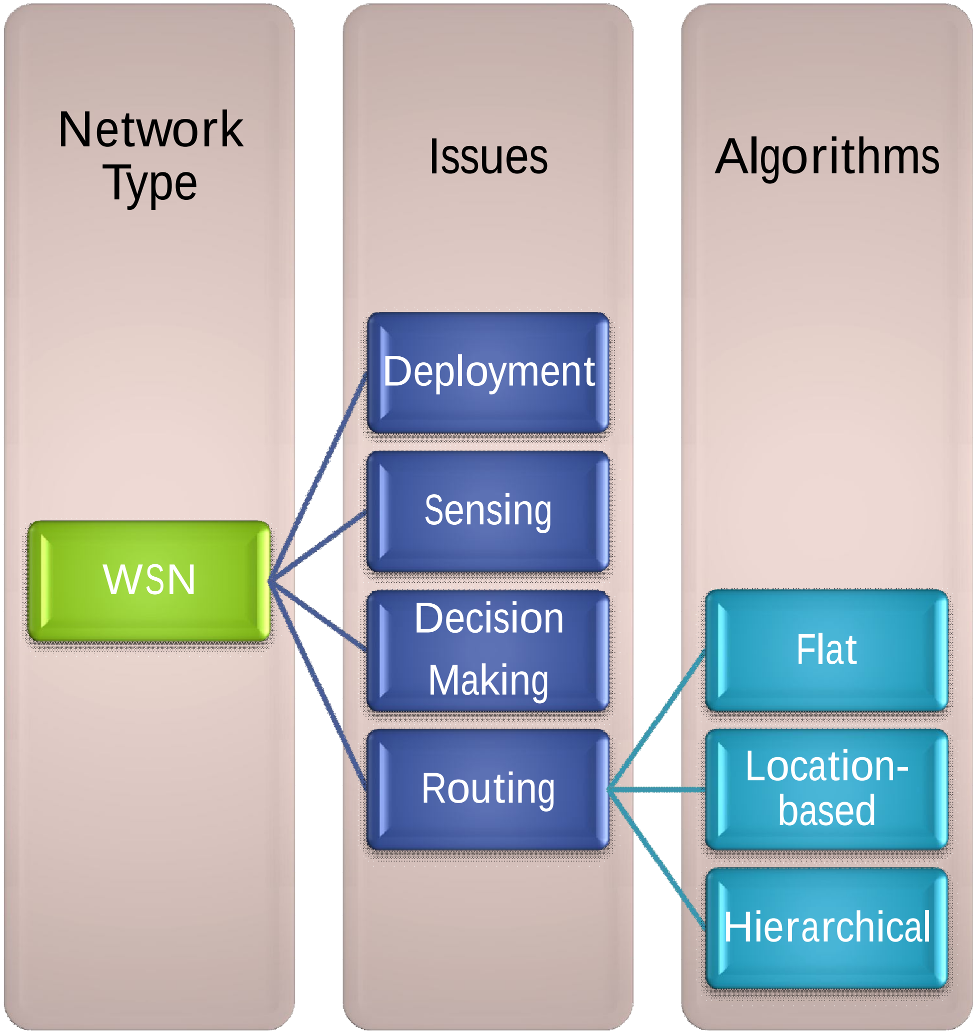
Conclusion (2/2)

- Assumed that the communication environment is contention and error free.
- In a contention-free environment, the algorithm has a time complexity of $O(k_1 + k_2 + ... + k_h)$, *a* significant improvement over the many $O(\boldsymbol{n})$ *clustering* algorithms in the literature.
- The algorithm is suitable for networks of large number of nodes.

Future Work

- Consider an underlying medium access protocol and investigate how that would affect the optimal probabilities of becoming a CH and the run-time of the algorithm.

Thank You



Network Type
Issues
Algorithms
WSN
Deployment
Sensing
Decision Making
Routing
Flat
Location-based
Hierarchical