SEP: A Stable Election Protocol for clustered heterogeneous wireless sensor networks

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Joint work with

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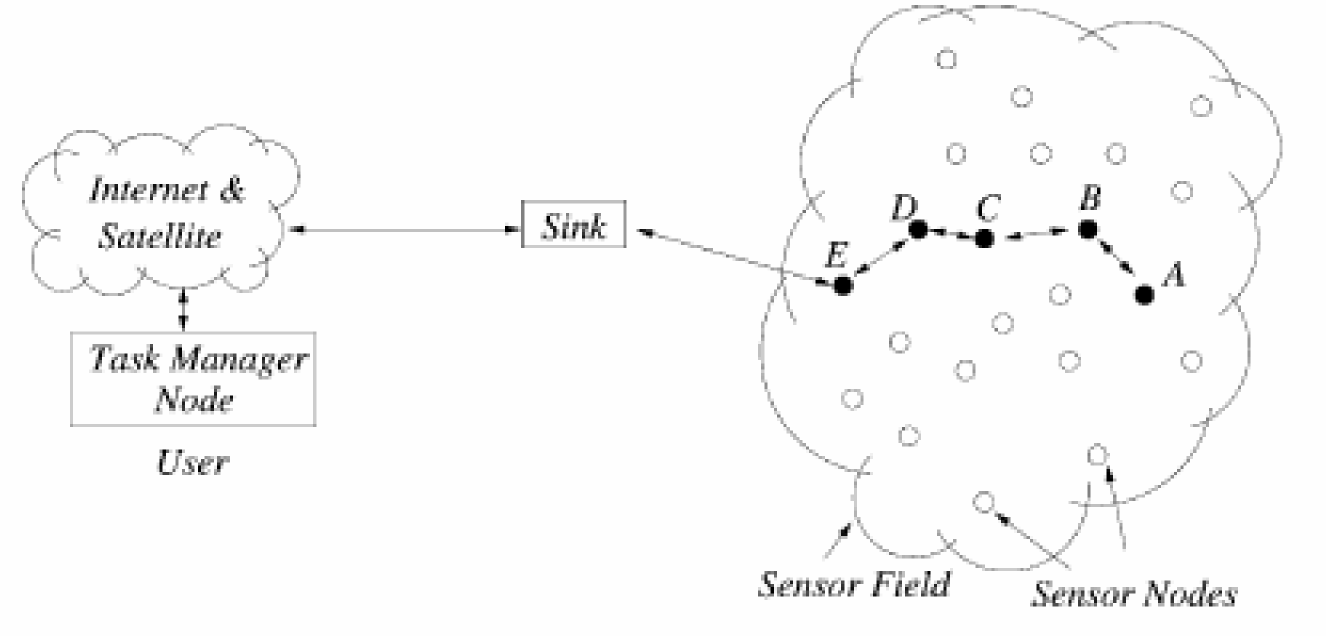
Heterogeneous WSN

- Nodes have different energy levels
- Initial setting, after some operation time, or after re-energizing some sensors

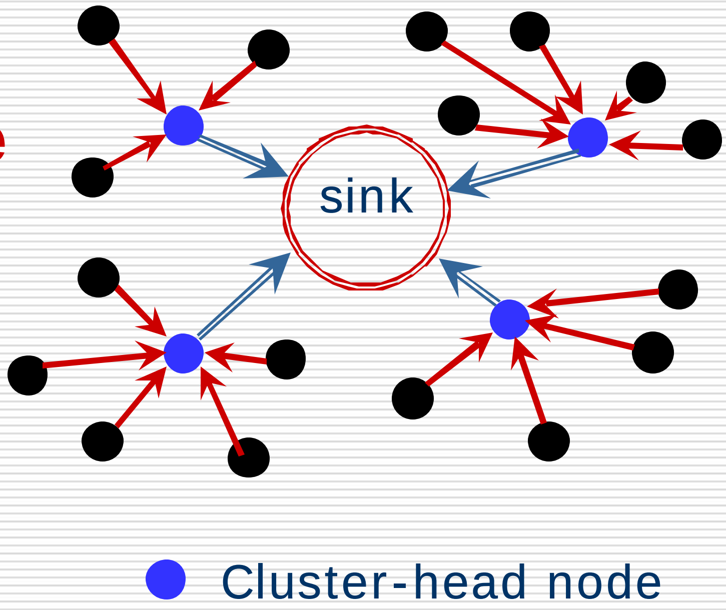


Routing

- **Goal:**
  prolong network lifetime/coverage

- Direct transmission to sink
- Min-energy routing
- **Sensing process can become biased**

- LEACH – Low Energy Adaptive Clustering Hierarchy [Heinzelman *et al.*, 2000]



Selecting Cluster-heads in LEACH

- Node *i* chooses random number, s, between 0 and 1
- If $s < T(i)$, node *i* becomes a cluster head in current round where:

$$T(i) = \begin{cases} \dfrac{P}{1 - P \times (r \bmod \frac{1}{P})} & \text{if } i \text{?} G \\ 0 & \text{otherwise} \end{cases}$$

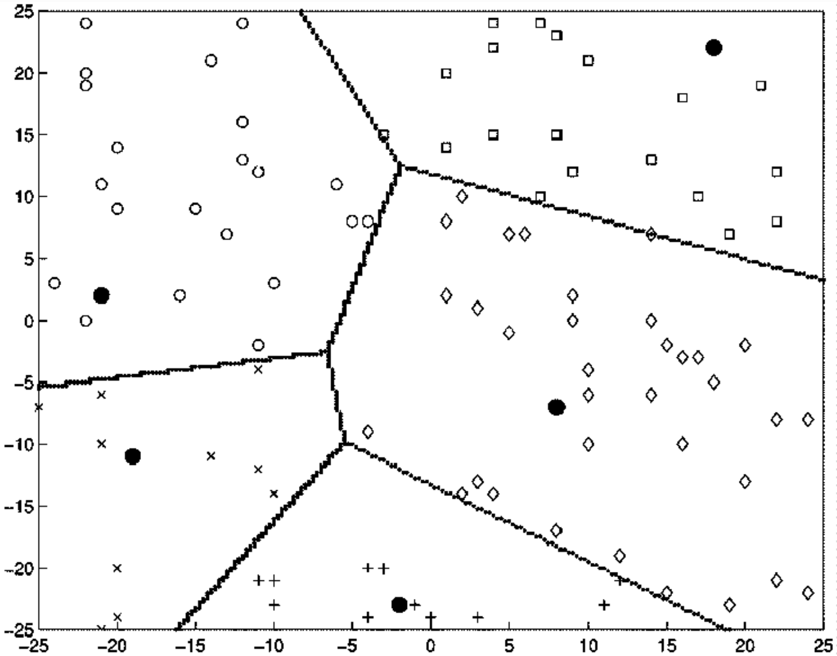
where:

P = desired percentage of cluster heads

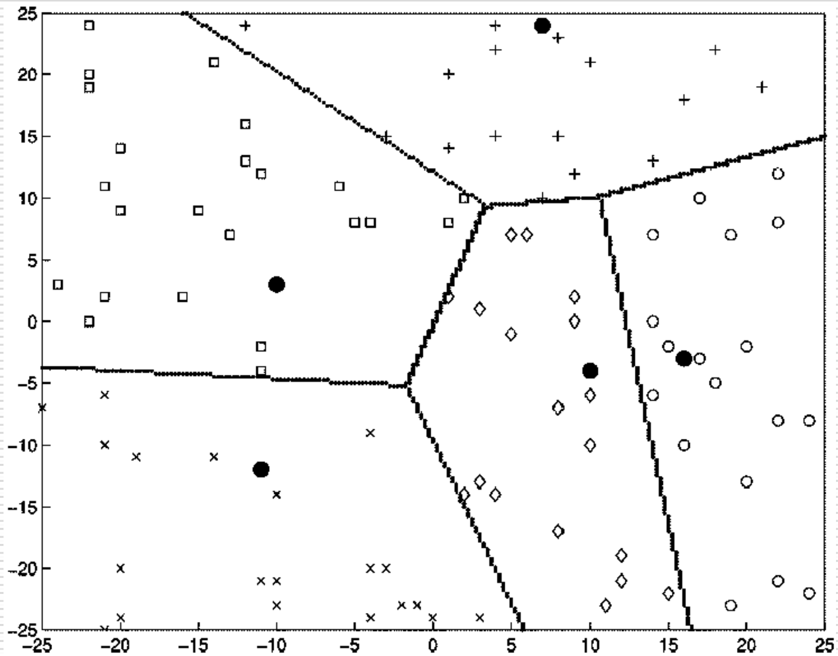
G = set of nodes that have not been a cluster head in the last $1/P$ rounds

- Each node is elected cluster-head once every 1/P rounds (epoch length)
- On average, $n \times P$ nodes elected per round
  - *n* = total number of nodes

Rotating Cluster-heads



Round r

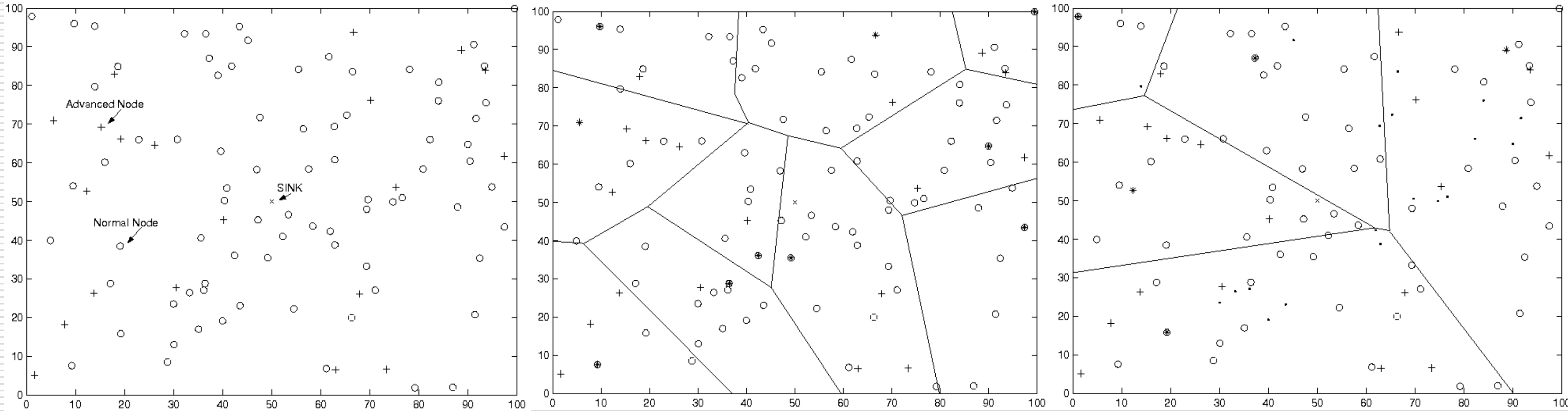


Round $r + 1$

When all nodes start with the same energy level (i.e., homogeneous setting), nodes “randomly” die and within a short period

But in a heterogeneous environment…

- The result of initial setting or evolution of the sensor network's operation
  - "advanced" node has α times more energy than "normal" node
- Once the first node dies, feedback and cluster-head election stays **unreliable** for a long time
  - advanced nodes don't get elected as often as they should

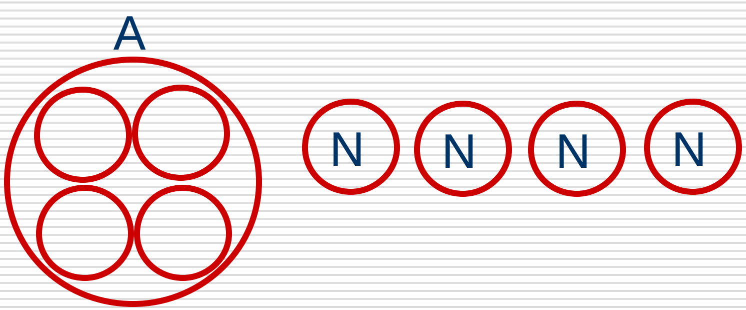


Naïve Modification to LEACH

- View network as homogeneous
  - Every "virtual" node is "normal" with unit energy
  - We have $n + \alpha \times m \times n = n(1 + \alpha \times m)$ "virtual" nodes
    - m = fraction of nodes that are advanced
- Extend epoch length to $(1+\alpha \times m)/P$ rounds
- **Hope is:**
  - Each normal node is elected cluster-head once every epoch
  - Each advanced node is elected cluster-head $(1+\alpha)$ times every epoch
    - This ensures well balanced energy consumption

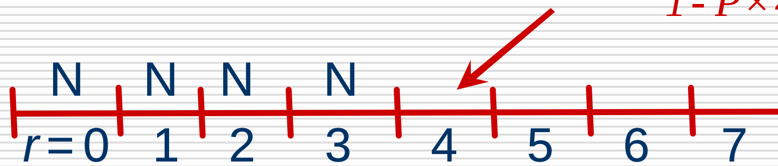
Problem with Naïve Solution

- Probability of electing an advanced node is not weighted by its additional energy
  - advanced nodes may be underutilized
  - Lifetime is prolonged, but time until the first node dies can still be short!



$$n = 5, m = 1/5, a = 3, P = 1/5$$

"A" node elected with probability $T(A) = \frac{P}{1 - P \times 4}$



Our SEP (Stable Election Protocol)

- **Idea:** force each advanced node to be elected every sub-epoch of length $(1+\alpha \times m)/P\ /(1+\alpha)$ rounds
- Probability of a normal node getting elected as cluster-head is P_{normal}
- Probability of an advanced node getting elected as cluster-head is $P_{advanced}$
- Average number of nodes elected per round = $n \times P$

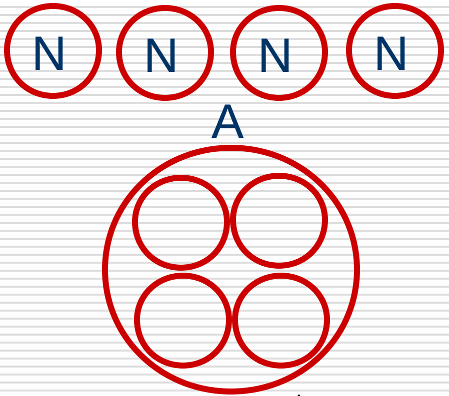
$$P_{normal} = \frac{P}{1+a\times m}$$

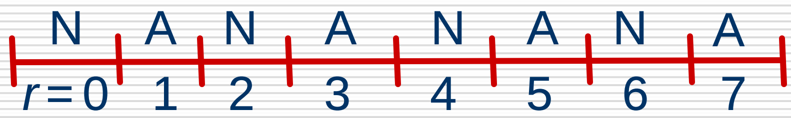
$$T(i) = \begin{cases} \dfrac{P_{normal}}{1-P_{normal}\times\left(r \bmod \frac{1}{P_{normal}}\right)} & \text{if } i\ ?\ G_{normal} \\ 0 & \text{otherwise} \end{cases}$$

$$P_{advanced} = \frac{P}{1+a\times m}(1+a)$$

$$T(i) = \begin{cases} \dfrac{P_{advanced}}{1-P_{advanced}\times\left(r \bmod \frac{1}{P_{advanced}}\right)} & \text{if } i\ ?\ G_{advanced} \\ 0 & \text{otherwise} \end{cases}$$

Numerical Example





Our SEP Scheme

$$n = 5, m = 1/5, a = 3, P = 1/5$$

$$P_{normal} = \frac{P}{1 + a \times m} = \frac{1/5}{1 + 3 \times 1/5} = \frac{1}{8}$$

$$T(i) = \begin{cases} \frac{P_{normal}}{1 - P_{normal} \times (r \bmod \frac{1}{P_{normal}})} & \text{if } i\ ?\ G_{normal} \\ 0 & \text{otherwise} \end{cases}$$

$$P_{advanced} = \frac{P}{1 + a \times m}(1 + a) = \frac{1}{8}(1 + 3) = \frac{4}{8}$$

$$T(i) = \begin{cases} \frac{P_{advanced}}{1 - P_{advanced} \times (r \bmod \frac{1}{P_{advanced}})} & \text{if } i\ ?\ G_{advanced} \\ 0 & \text{otherwise} \end{cases}$$

Performance Measures

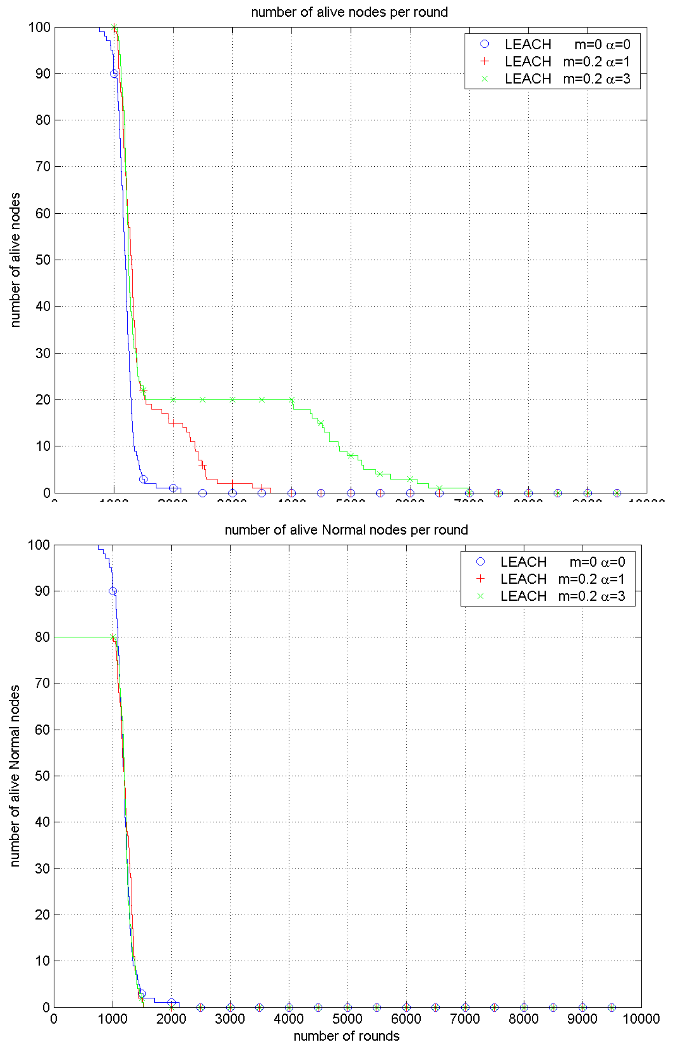
- Stability Period
  - Time until death of the first node
- Network lifetime
  - Time until death of the last alive node
- Number of cluster-heads per round
  - Nodes which will directly send aggregated information to the sink
- Number of alive nodes of each type per round
- Throughput
  - Rate of data reporting to cluster-heads and to sink

Simulation Model

- Two networks
  - 100 nodes uniformly distributed over 100mx100m
  - 900 nodes uniformly distributed over 300mx300m
- Sink is in the center of the sensor field
- Message size = 4000 bits
- Initial energy for a normal node = 0.5 Joules
- Energy consumed depends on radio characteristics

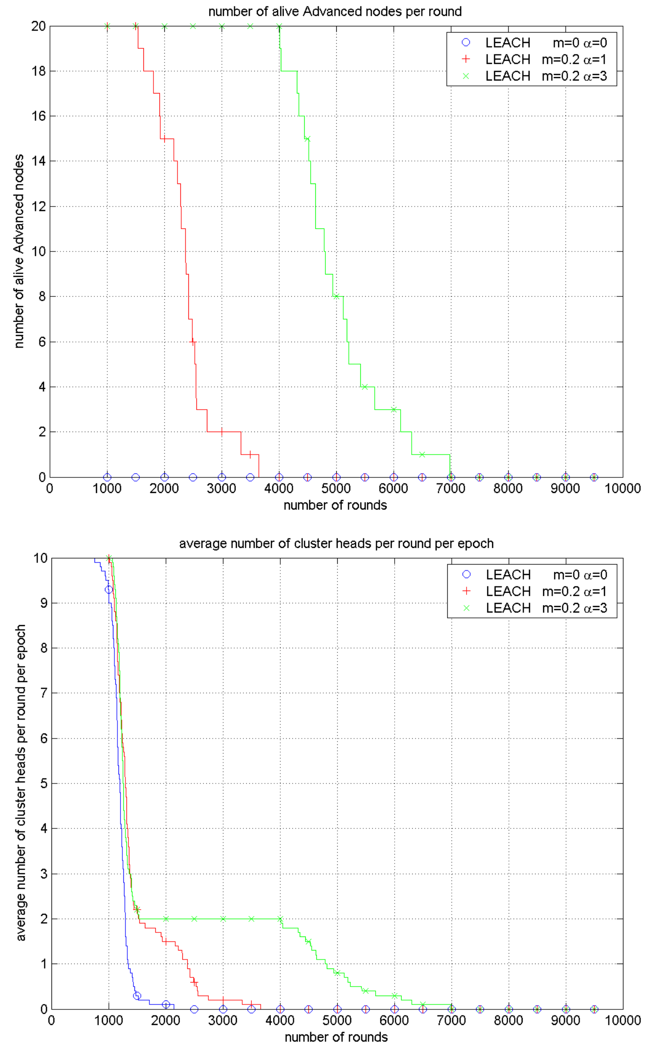
Results for LEACH

- LEACH does not take full advantage of the extra energy of advanced nodes
- Normal nodes die very fast
  - Sensing field becomes sparse very fast
  - Election process becomes unstable fast
    - Throughput is low



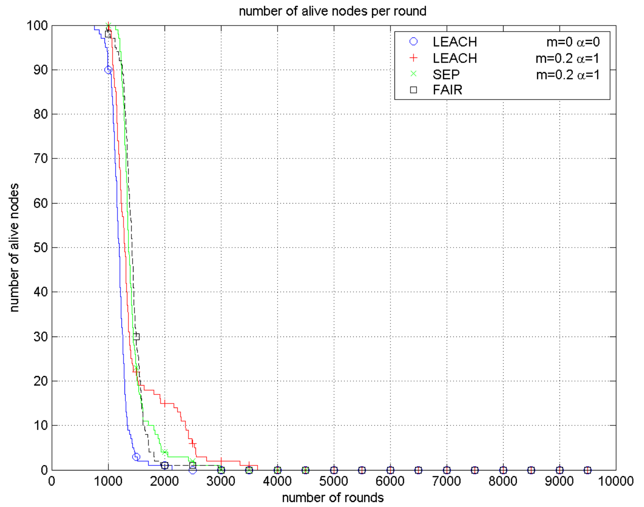
Results for LEACH (cont'd)

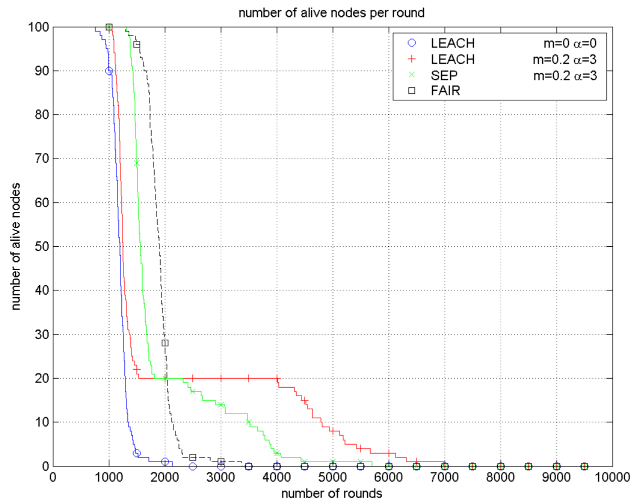
- Advanced nodes die very slowly
  - They are not elected as often as they should
    - Throughput is low



Results for SEP

- SEP takes full advantage of the extra energy of advanced nodes
  - Stable region increases by up to 26% over LEACH
  - Higher throughput

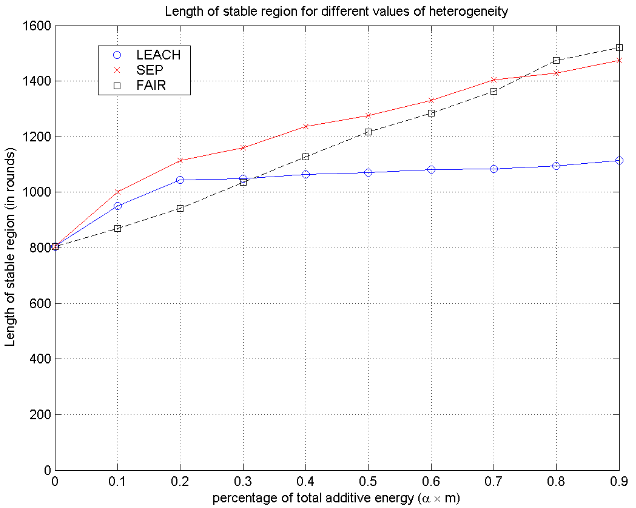


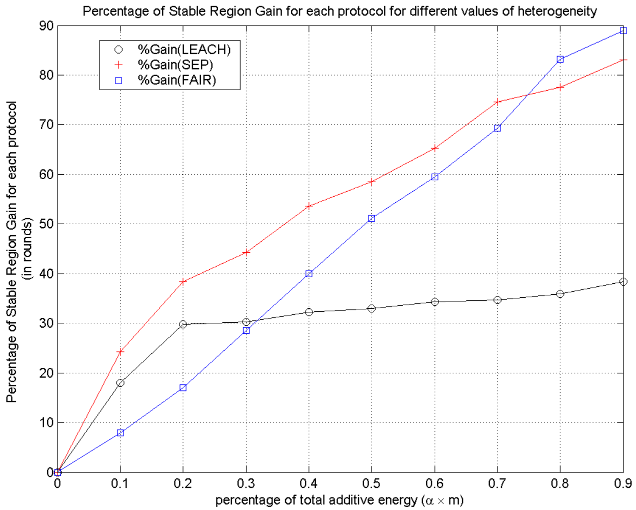


- Advanced nodes follow the death process of normal nodes
  - Smaller unstable region

Sensitivity of SEP

- Performance depends on the product $m \times a$
- FAIR: ideal distribution of extra energy
- Gain in stability period (over system with no extra energy, i.e., $m=0$ & $\alpha=0$) is maximized under SEP
  - SEP > LEACH
  - SEP > FAIR for up to 75% relative extra energy





Conclusion

- SEP is heterogeneous-aware
  - Cluster-heads elected based on node's energy relative to that of others
- SEP is scalable and dynamic
  - Even normal node can be elected
  - No global knowledge required at every round
  - No prior distribution of energy levels assumed

- Study SEP for more than 2 hierarchical levels and more than 2 types of nodes
- Implementation in Berkeley/Crossbow motes
- Deployment issues
  - Dynamic updates of weighted election probabilities
  - Integration with power-aware MAC protocols
  - ...

For more information, please check
http://csr.bu.edu/sep/