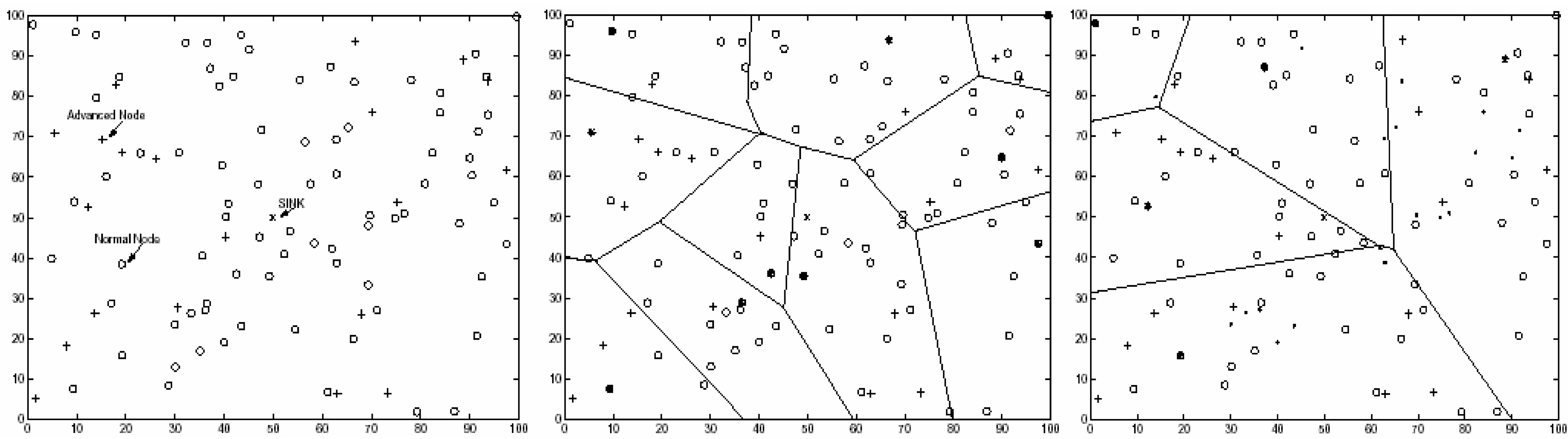
SEP: A Stable Election Protocol for clustered heterogeneous wireless sensor networks

Georgios Smaragdakis, Ibrahim Matta and Azer Bestavros – Computer Science Department, Boston University

Introduction

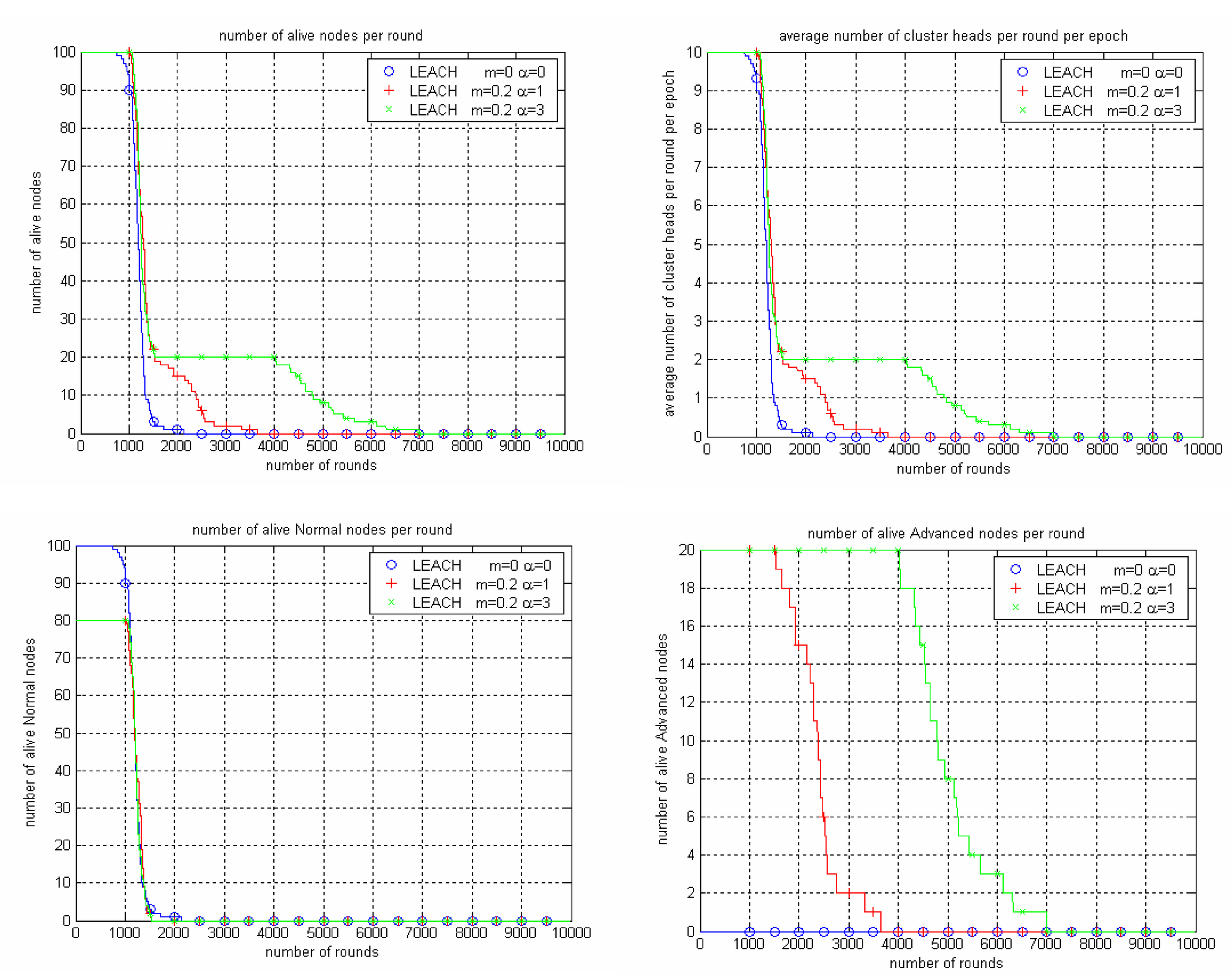
We study the impact of heterogeneity of nodes, in terms of their energy, in wireless sensor networks that are hierarchically clustered. In these networks some of the nodes become cluster heads, aggregate the data of their cluster members and transmit it to the sink. We assume that a percentage of the population of sensor nodes is equipped with additional energy resources - this is a source of heterogeneity which may result from the initial setting or as the operation of the network evolves. We show that the behavior of such sensor networks becomes very unstable once the first node dies, especially in the presence of node heterogeneity.



n nodes, m% of nodes are equipped with a% more energy — before the first node dies — after the death of some nodes

Related Work

Classical clustering protocols assume that all the nodes are equipped with the same amount of energy and as a result, they cannot take full advantage of the presence of node heterogeneity.



How Clustered Sensor Network Protocols (LEACH) work

The protocol guarantees that every node will become a cluster head exactly once every $\frac{1}{p_{opt}}$ rounds. We refer to this number of rounds, as *epoch* of the clustered sensor network. p_{opt} is an optimal percentage (determined a priori) of nodes that has to become cluster heads in each round

Initially each node can become a cluster head with a probability p_{opt}. On average, $n \times p_{opt}$ nodes must become cluster heads per round per epoch. Nodes that are elected to be cluster heads in the current round can no longer become cluster heads in the same epoch. The non-elected nodes belong to the set G and in order to maintain a steady number of cluster heads per round, the probability of nodes $\in$ G to become a cluster head increases after each round in the same epoch. The decision is made at the beginning of each round by each node s $\in$ G independently choosing a random number in [0,1]. If the random number is less than a threshold T(s) then the node becomes a cluster head in the current round. The threshold is set as:

$$T(s) = \begin{cases} \dfrac{p_{opt}}{1 - p_{opt}\left(r \bmod \frac{1}{p_{opt}}\right)} & s \in G \\ 0 & otherwise \end{cases}$$

where r is the current round number. The election probability of nodes $\in$ G to become cluster heads increases in each round in the same epoch and becomes equal to 1 in the last round of the epoch. Note that by round we define a time interval where all clusters members have to transmit to the cluster head once.

http://csr.bu.edu/sep

Our Protocol

We propose SEP, a heterogeneous-aware protocol to prolong the time interval before the death of the first node (we refer to as *stability period*), which is crucial for many applications where the feedback from the sensor network must be reliable. SEP is based on weighted election probabilities of each node to become cluster head according to the remaining energy in each node.

Analysis

In the heterogeneous scenario the average number of cluster heads per round per epoch is equal to n(1+am) p_{nrm}(because each virtual node has the initial energy of a normal node). The new thresholds for normal and advanced nodes are respectively:

$$T(s_{nrm}) = \begin{cases} \dfrac{p_{nrm}}{1 - p_{nrm}\left(r \bmod \frac{1}{p_{nrm}}\right)} & s_{nrm} \in G' \\ 0 & otherwise \end{cases}$$

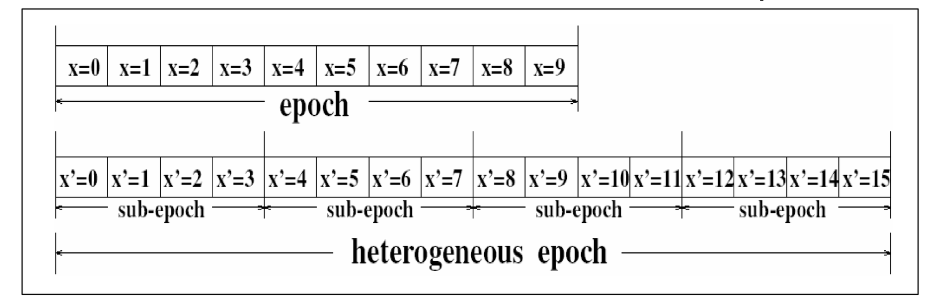
where $p_{nrm} = \frac{p_{opt}}{1+am}$ is the weighted probability for normal nodes, r is the current round and G' is the set of normal nodes that have not become cluster heads the last $\frac{1}{p_{nrm}}$ rounds of the epoch.

$$T(s_{adv}) = \begin{cases} \dfrac{p_{adv}}{1 - p_{adv}\left(r \bmod \frac{1}{p_{adv}}\right)} & s_{adv} \in G'' \\ 0 & otherwise \end{cases}$$

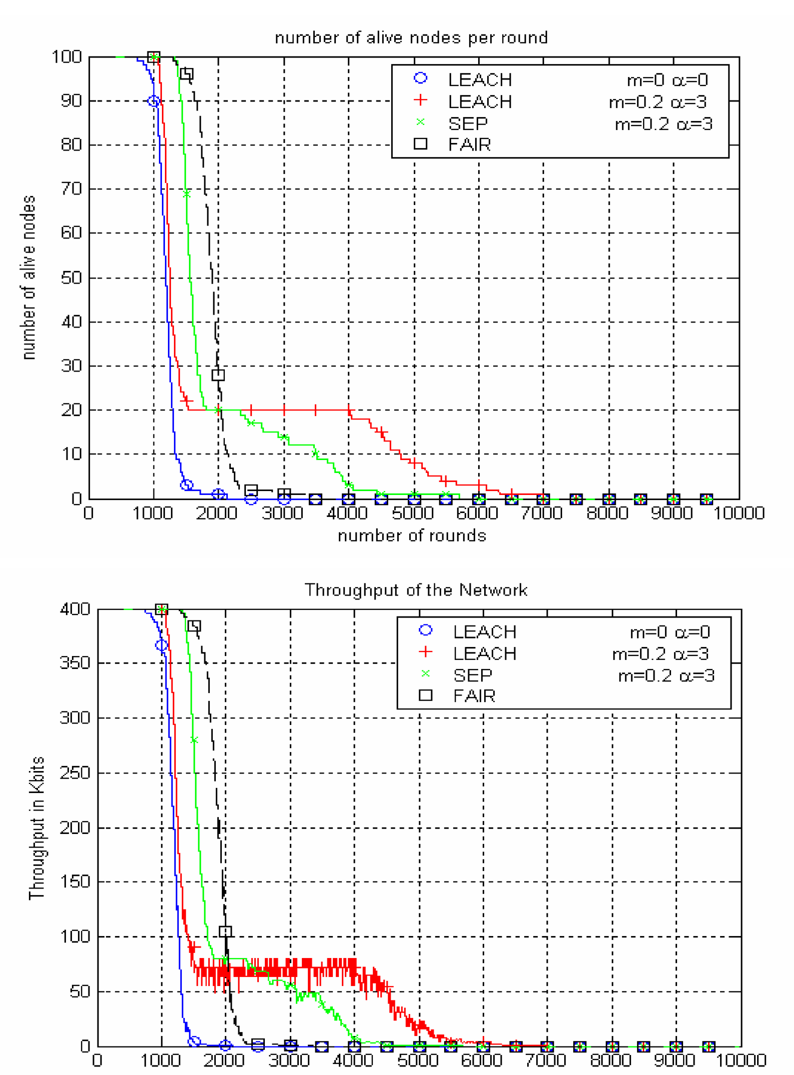
where $p_{adv} = \frac{p_{opt}(1+a)}{1+am}$ is the weighted probability for normal nodes, r is the current round and G'' is the set of normal nodes that have not become cluster heads the last $\frac{1}{p_{adv}}$ rounds of the epoch.

Thus the average total number of cluster heads per round per heterogeneous epoch is np_{opt} .

Main Results



- Our SEP protocol successfully extends the stable region.
- Due to extended stability, the throughput of SEP is higher.
- The performance of SEP is observed to be close to that of an ideal upper bound
- SEP is more resilient than LEACH in judiciously consuming the extra energy of advanced nodes
  - yields longer stability region for higher values of extra energy.
- SEP is light and scalable for large and small networks (it is not GPS based solution).



Sensitivity Study