Greedy algorithms for selective activation in Wireless Sensor Networks

Maximum points 100

General information

Maximum group size 3.

Any programming language can be used for the implementation.

The project reports should be submitted in hardcopy to the Instructor the day of the deadline. Additionally, the reports and the code should be submitted to the TA electronically the day of the deadline.

The project should be discussed with the TA within 1 week from the deadline of the second report.

Wireless Sensor Networks

A Wireless Sensor Network (WSN) is composed by small devices endowed with sensing and communication capabilities. Modern devices can collect physical quantities such as temperature, pressure or light intensity, as well as images and videos.

Application of WSNs include hazard and inaccessible fields, where sensors cannot be deployed manually. As a result, sensors are generally thrown from an aircraft over the Area of Interest (AoI), generating a random deployment.

Sensors have limited energy availability. In order to prolong the coverage of the AoI for a long period of time, sensors are generally redundantly deployed, i.e. not all sensors need to be active simultaneously in order to cover the AoI at the maximum extent. In order to save energy, only a subset of the sensors can be kept active, ideally the minimum subset that would prevent a loss in coverage. The problem of finding the set of sensors to be kept active is known as selective activation.

The goal of this project is to investigate the performance of greedy algorithms for selective activation in WSNs.

Network model and problem formulation

A set of $S$ sensors are randomly deployed in an Area of Interest (AoI). For each sensor $s$ we keep track of its position $(x_s, y_s)$ and of its energy level $e_s$. Initially, $e_s = 300$ for each sensor. Each sensor has a sensing radius $R$, and it can cover a disk of radius $R$ centered at the sensor itself. The number of sensors deployed is $N$.

The base station determines the set of active sensors periodically, i.e. at each round $t$, by executing a selective activation algorithm that returns a set $A_t$. Let $S_t$ be the set of sensors alive at round $t$, i.e. for each sensor $s$ in $S_t$,
The set $A_t$ returned by the algorithm is such that $A_t \subseteq S_t$, that is all sensors are alive. Let $\text{Cov}(A_t)$ be the coverage provided by the sensors in $A_t$, that is the union of the sensing ranges of all the sensors in $A_t$. The algorithm must return a set $A_t$ s.t. it provides the same coverage of $S_t$, that is $\text{Cov}(A) = \text{Cov}(S_t)$. In other words, by selecting a subset of sensors to be active, we do not want to lose any coverage.

When a set of sensors $A_t$ is selected for a period $t$ to be active, all sensors in this set consume one unit of energy. On the contrary, the remaining sensors in $S \setminus A_t$ consume no energy.

Note: We say a sensor is alive at round $t$ if its residual energy is greater than 0. We say that a sensor is active at round $t$, if the selective activation algorithm decides to keep it active. An active sensor needs to be alive.

**Algorithm design**

The project requires to design a greedy algorithm that will be compared with some base line approaches. The goal of the algorithm is to determine the set $A_t$ for each time step $t$.

In order to determine if a sensor is redundant, i.e. it can be turned off without losing coverage, we can use the following method. Given two sensors $s_i$ and $s_j$, if the distance between them is less than $R$, then the intersections between their sensing disks generate two intersection points. The following Theorem provides a sufficient condition for redundancy.

**Theorem:** Consider a set $S$ of sensors with sensing radius $R$ deployed over the AoI. Consider the set $P$ of all intersection points generated by the sensing disks of the sensors in $S$. A sensor $s$ is redundant if for each intersection point $p$ that falls in $s$'s sensing range, there exists another sensor $q$ in $S$ able to cover $p$, that is the distance between $q$ and $p$ is less than $R$.

The previous theorem can be used to determine if a sensor is redundant by simply checking if there are other sensors that can cover the intersection points in its sensing range.

The greedy algorithm should follow a criteria to select the set of active sensors, ensuring that the set returned as output is composed only by alive sensors and provides the same coverage as all sensors currently alive in the network.

The greedy algorithm should be compared with the following approaches.

**All active:** This algorithm just returns $S_t$ for each round $t$.

**Random-bottom-up:** This algorithm starts from an empty set of active sensors $A$. It iteratively selects a sensor $s$ among those that are alive to be added to $A$. The sensor $s$ is added to $A$ only if the sensor covers some intersection points that are currently not covered by the sensor in $A$.

**Random-top-down:** This algorithm starts from a set of active sensors $A$ equal to the set of alive sensors $S_t$. It iteratively pick at random a sensor $s$ in $A$. The sensor $s$ is removed from $A$ if it is redundant (with respect to the sensors in $A$).

We are interested in comparing the performance of the algorithms in different operative settings as described below.
Implementation and evaluation

The AoI can be assumed to be a square of size 50 x 50m². Assign to each node a random position (x, y) by selecting a random value for both x and y in the interval (0,50). The initial energy for each sensor is 300 energy units, and 1 energy unit is consumed per round if a sensor is active in that round. The sensing range of its sensor is set to R = 5m.

Performance over time

This set of experiments wants to study the performance of the algorithms over time.

These graphs should be generated for different values of N, that is N = 50, 100, and 500. For each graph there should be four lines, each one representing one of the algorithms. The total number of graphs is 12.

- Percentage of alive sensors (sensors with residual energy > 0)
- Percentage of active sensors (sensors selected by the algorithm)
- Average residual energy
- Percentage of coverage

Note: To calculate the coverage provided by a set of sensors you can use the Montecarlo approach. Specifically, you select M random locations in the AoI, and count the percentage of these that are covered. If M is sufficiently large, the calculated amount is close to the actual coverage.

Lifetime

This set of experiments wants to study the performance of the algorithms in terms of lifetime as we increase the number of available sensors from 50 to 500, with an increase step of 50. The network lifetime is the round at which the network cannot cover more than 50% of the AoI.

A single graph should be generated, with the number of sensors on the x axis and the lifetime on the y axis. The graph should have 4 lines, one for each algorithm.

Reports

Two reports should be prepared. The first report does not require implementation and should include at least the following sections:

- Abstract: Summary of the following sections
- Introduction and motivation: Overview of Wireless Sensor Networks and selective activation.
- Proposed solutions: Pseudo-code, description and complexity analysis of the proposed algorithms, including baseline approaches.
- Plan of experiments: Description of the methodology which is planned to use in the experiments, significance and expected results.

The second report requires implementation and describes the implementation and results. It should include at least the following sections:
- Abstract: Summary of the following sections and results
- Implementation: Description of the methodology used for implementing the proposed solutions (e.g. relevant classes and data structures, structure of the program, etc.).
- Experiments: Description of the experiments performed and obtained results. Results should be represented in a graphical form as well as discussed in the writing. It is fundamental to discuss meaningful conclusions comparing the performance of the different solutions.
- Conclusions: Summary of the work and final considerations.