A STEP TOWARD RESEARCH ON THE LIFETIME OF A WIRELESS SENSOR NETWORK FROM CS1

Paul Wiechmann, Department of Computer Science, University of Central Oklahoma
Advisor: Dr. Myung Ah Park, Department of Computer Science, University of Central Oklahoma

ABSTRACT

In this work, the first steps taken from CS1 towards research on the lifetime of a single-hop wireless sensor network is presented. The network considered in this work consists of a grid space populated by randomly located immobile targets and several roaming sensors. Sensors detect targets in the grid, periodically gather data, process it, and transmit a message to the base station. Parameters such as the number of targets, the ratio of energy consumption, the size of the grid, and the movement speed of the sensors are considered, and the impact of these parameters on the lifetime and energy efficiency of the network is investigated through simulation. The average network lifetime is also derived through mathematical analysis.

INTRODUCTION

Wireless sensor networks have been extensively studied in the literature mainly because of their versatile applications that do not require human operation. Common applications include military surveillance, facility monitoring, and environmental monitoring. The main characteristics of a wireless sensor network are as follows [1]:

- It consists of a large number of sensor nodes (dense network)
- Sensors coordinate among themselves to achieve a goal specific to an application.
- Sensors periodically record data, process it, and transmit it to the base station (cooperative effort with on-board processing)
- The position of sensor nodes does not need to be engineered or predetermined, so sensors are usually randomly deployed in inaccessible terrain or disaster relief operations (random deployment)

Although they are versatile, wireless sensor networks have some constraints. Sensors are limited in power, computational capacities, and memory. They are also prone to failure.

NETWORK LIFETIME & ENERGY EFFICIENCY

Because of the limited power capacity of sensors, there has been extensive research with different approaches into the lifetime of wireless sensor networks. The network lifetime can be defined in various ways based on application scenarios. Here are the examples proposed in the literature [2].

- The time of the first node failure
- The time of a certain fraction of surviving nodes
- Mean expiration time

- Acceptable packet delivery rate
- The number of alive data flows

In this work, a sensor surveillance system is simulated where a wireless sensor monitors a target and sends data to a base station. The network lifetime is defined as the time of the first node failure. Energy efficiency is also defined as the ratio of energy consumption for data processing to energy consumption for idling. It is well known that sensors consume more energy when idly listening for possible traffic [3]. There has therefore been considerable research in medium access control conducted to reduce energy consumption when sensors are idle. The main idea put forth by the literature has been the utilization of a sleeping mode, and finding the most efficient schedule between sleeping mode and awake mode in coordination with other sensors.

NUMERICAL RESULTS

The simulation environment is as shown in Fig. 1. As illustrated in the figure, the network is spread over a grid layout. The base station has a fixed location at the center. The targets are randomly placed at the beginning of the simulation and remain at the same locations throughout the simulation. A number of sensors are also randomly placed in the grid at the beginning of the simulation. Each sensor has the initial energy of 2 Joules.

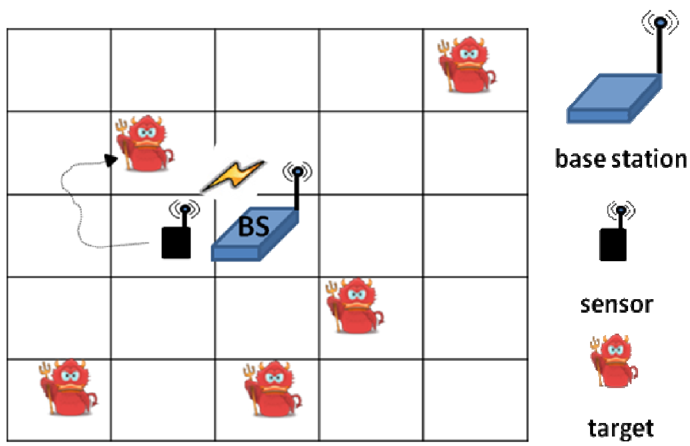

Fig. 1 Simulation Environment

Each sensor is capable of random movement and target detection. If a sensor moves to a cell in which there is a target, the sensor has to stay at least 5 seconds. It also detects target information every 1 second for a random time. Every time the sensor detects target information, it generates a message and sends it to the base station. The energy and the time required for this activity, i.e. detecting the target, processing information, and sending a message is 40.5μJ and 30ms, respectively. If a sensor moves into a cell in which there is no target, it stays in that cell, idling for a random time before it moves to another cell. Idling requires an energy expenditure of 90μJ per second because it has to listen to the base station and other sensors.

A sensor is allowed to remain in a cell for the maximum time of 30 seconds regardless of whether the cell contains a target. After a sensor has spent a random time in a cell, it randomly selects an adjacent cell and moves to that chosen cell. For simplicity, the moving time is assumed to be zero.

A. Varying number of targets

As shown in Fig. 2, sensor lifetime increases as target density increases, as does the disparity between minimum and maximum lifetimes. As the number of targets increases, the average network lifetime grows linearly at approximately 12 minutes per target. The increase is due to the ratio of energy consumption between idling and sensing targets. The sensor consumes more energy as it idles than when it detects targets. As the target density increases, the sensors spend more time detecting targets, lowering the energy consumption.

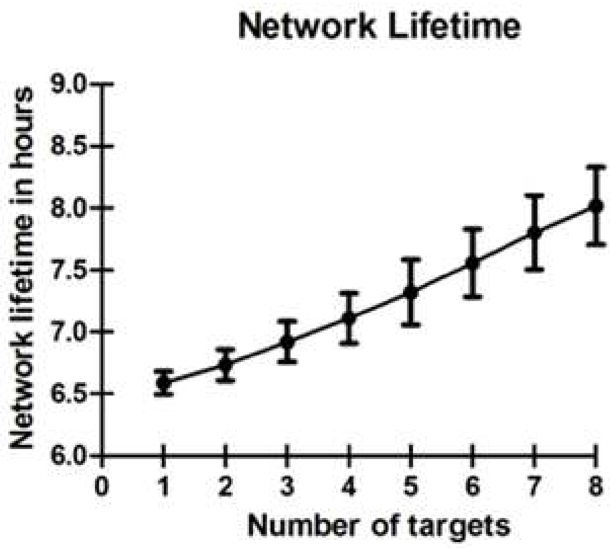

Fig. 2 Network lifetime vs. number of targets

B. Varying active to idle energy consumption ratio

Sensor lifetime decreases exponentially as the ratio between active and idle energy consumption increases as shown in Fig. 3. The energy expenditure for sensing a target was kept constant while the energy expenditure for idling was varied between 90µJ and 20µJ with a granularity of 5µJ. The number of targets was also kept constant at 5.

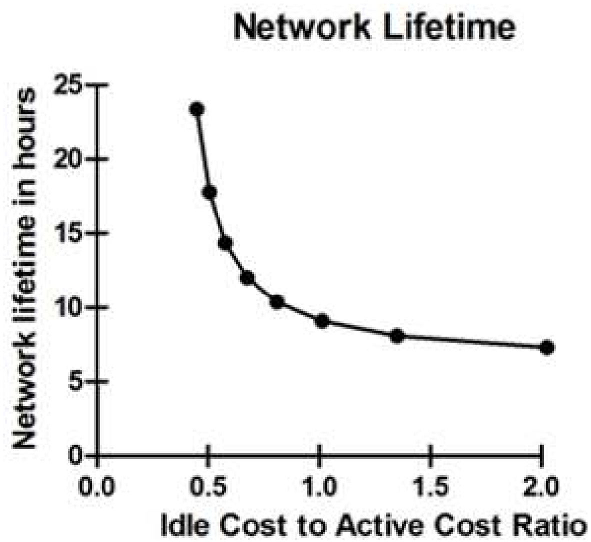

Fig. 3 Network lifetime vs. Energy consumption ratio

C. Varying number of targets and energy consumption ratio at the same time

As shown in Fig. 4, sensors with active to idle energy consumption ratios greater than 1 had longer lifetimes at low target densities, but decreased linearly as target density increased, while the lifetime of sensors with ratios less than 1 increased linearly as target density increased. The rate of increase in network lifetime for sensors with ratios of 0.45 is approximately 12 minutes per target. The rate of decrease in network lifetime of sensors with ratios of 1.5 is approximately 24 minutes per target. The rate of decrease in network lifetime of sensors with ratios of 2.0 is approximately 60 minutes per target.

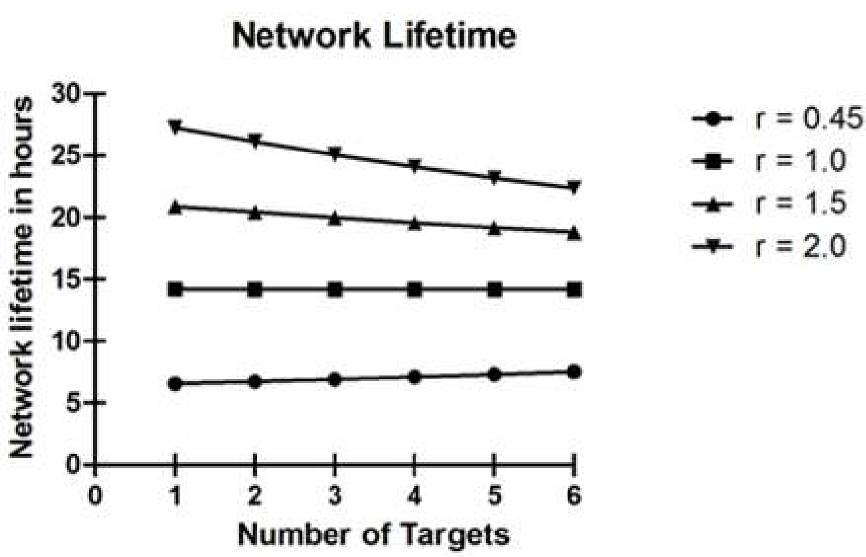

Fig. 4 Network lifetime vs. number of targets and energy consumption ratio

D. Varying grid size

Sensor lifetime decreases exponentially as the size of the grid increases, thus lowering target density as shown in Fig. 5. The number of targets was kept constant at 5, while the number of cells was varied between 20 and 85 meters with a granularity of 5. The sparser target distribution as the grid size increases means that a sensor will idle more frequently and consume energy more quickly.

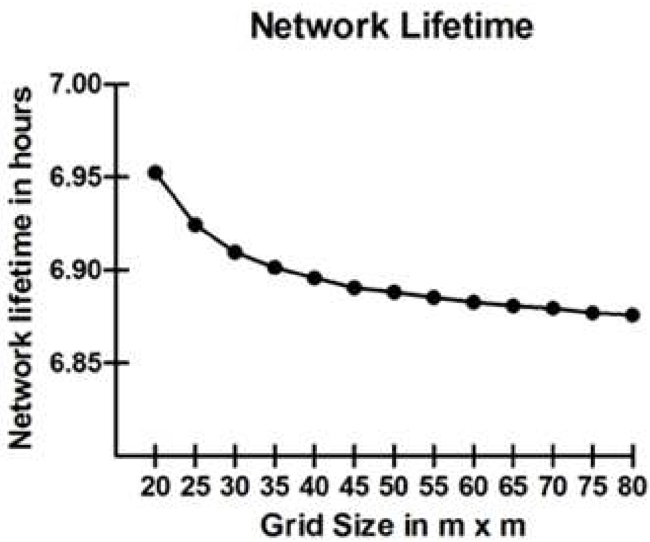

Fig. 5 Network lifetime vs. grid size

MATHEMATICAL ANALYSIS OF AVERAGE NETWORK LIFETIME

In order to derive the average network lifetime through mathematical analysis, the following terms are used:

- L = Average network lifetime
- N = Average number of cells visited before a sensor dies.
- X = Random time spent in a cell.
- X_p = Average time spent in a cell with a target.
- X_q = Average time spent in a cell without a target.
- X_{max} = Maximum time spent in a cell.
- $E_{initial}$ = Initial energy of the sensor.
- E_c = Average energy spending at a given cell.
- E_c^p = Average energy consumption at a cell containing a target.
- E_c^q = Average energy consumption at a cell not containing a target.
- p = Probability that the sensor will detect a target at a given cell.
- q = Probability that the sensor will not detect a target at a given cell.

E_c^p and E_c^q are calculated by multiplying a random time spent in a cell by the energy expenditure required for sensing a target and idling, respectively. 5 seconds is added to the random time for X_p to account for the minimum time it is required to spend in a cell with a target:

$$E_c^p = (5 + X) * 40.5\mu J$$
$$E_c^q = X * 90\mu J$$

X_{max} and $E_{initial}$, are predetermined constants:

$$X_{max} = 30s$$
$$E_{initial} = 2{,}000{,}000\mu J$$

X_p and X_q are calculated based on assumptions.

$$X_p = 5 + [(X_{max} - 5s) / 2] = 17.5s$$
$$X_q = X_{max} / 2 = 15s$$

E_c is calculated, substituting X in E_c^p and E_c^q with X_p and X_q respectively:

$$E_c = (p * E_c^p) + (q * E_c^q) = (p * X_p * 40.5\mu J) + (q * X_q * 90\mu J)$$

N is calculated by dividing the initial energy by the average energy expenditure in a given cell:

$$N = E_{initial} / E_c$$

The average network lifetime can then be calculated by multiplying N by the average time spent in a given cell:

$$L = N * [(p * X_p) + (q * X_q)]$$

CONCLUSION

This work has been conducted in order to achieve an intermediate level of confidence in empirical concepts and skills in computer science beginning with CS1 [4]. For this purpose, the lifetime of wireless sensor networks was studied, and the impact of various parameters on the lifetime was investigated through simulation and mathematical analysis. For future work, utilization of a software package such as NS-2 is being considered, as well as more realistic constraints such as interdependent nodes and communication protocols, in order to create a more realistic simulation environment.

REFERENCES

[1] F. Akyildiz, W. Su, and Y. Sankarasubramaniam, A Survey on Sensor Networks, IEEE Communications magazine, 2002

[2] Q. Dong, Maximizing system lifetime in wireless sensor networks, Proc of the 4th international symposium on Information processing in sensor networks (IPSN), Los Angeles, CA, USA, Apr. 2005

[3] Wei Ye, John Heidemann, and Deborah Estrin, An Energy-Efficient MAC Protocol for Wireless Sensor Networks, IEEE INFOCOM 2002

[4] Grant Braught, Craig S. Miller, and David Reed, Core Empirical Concepts and Skills for Computer Science, SIGCSE'04, Mar3-7, 2004, Norfolk, Virginia, USA