UNIVERSITY OF WATERLOO

Department of Electrical and Computer Engineering

ECE 493-659 IOT and Intelligent Sensor Networks

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Assignment 2
Due Date: June 25th 2022 11:59PM

Instructions

- This assignment can be approached in groups. Each group consists of two or three students.
- If you are attempting this assignment as a group, then you are required to solve all questions. If you are doing it solo, then you can either ignore Question 4 (Synchronization and OMNet++), or attempt it as bonus.
- You should upload your answers as a PDF file on learn before 11:59pm of the deadline date. One submission per group.
- Attach any codes used for the assignment separately as a compressed file to the same dropbox
- You can use any programming language (Matlab and Python are preferred)
- Works with more than 30% similarity will not be marked
- Communicate any issues or concerns with the TAs.
- Deliverables: provided for each question
- Marking Scheme: provided for each question

  - Marks breakdown: provided in each question.
- As you may appreciate, I have eliminated the exam components from the evaluation criteria of this course. Furthermore, I allowed you to attempt the tasks of the assignments in groups. Thus, the complexity of the assignment is designed such that an adequate level of course material reinforcement is attained as well as to ensure that a comprehensive evaluation of your understanding is achieved. Good Luck!

Question 1: Transport and Application Layer Protocols (10 points)

1. (3 points) What is the goal of sensor management in WSN?
2. (5) Review the following paper and summarize it using 500 (min) to 700 (max) words.

Link

Sensor Management Using Relevance Feedback Learning" By: Chris Kreucher*, Keith Kastella and Alfred O. Hero III, IEEE Fellow.

http://web.eecs.umich.edu/~hero/Preprints/SM_draft091703.pdf Link to the article

A copy can be found in Assignment 2 folder

3. (2 points) Explain and compare, in your own words, the main attributes of the QMTT and COAP protocols. (Material on both protocols is posted on learn)

Question 2: Cognitive Sensor Networks (15 points)

1. (2 points) What is cognitive sensor networks?
2. (2 points) What makes them different from traditional sensor networks?
3. (2 points) Why are we interested in them?
4. (2 points) Briefly discuss challenges one faces in trying to realize cognition in IOT and WSN.
5. (2 points) Explain what is meant by spectrum sensing.
6. (5 points) identify and three spectrum sensing techniques. Summarize each one of them briefly. If you are to combine two of them in one implementation to achieve improved performance, which two of the three you have identified would you choose? Justify why.

Question 3: Time Synchronization (20 points)

5 points/part

- (a) **Refer to TDOA localization in a three-dimensional space**. Assume that five reference nodes are known at Node 1: (0,3,0), Node 2: (6,0,0), Node 3: (3,4,0), Node 4: (4, 3, 0), and Node 5: (0, 0, 8) respectively. Also, for node U, we know the following propagation times:
  $U_{11} = 0s, U_{12} = 1s, U_{13} = 0.7s, U_{14} = 0.7s, \& \ U_{15} = 1.7s$. The velocity of propagation is v.

  (i) Find the unknown location (x_U, y_U, z_U).

  (ii) Now assume that the propagation speed is known to be 8.7 m/s. Find the unknown location (x_U, y_U, z_U).

- (b) Node A sends a synchronization request to node B at 3150 (on node A's clock). At 3250, node A receives the reply from node B with a time stamp of 3120.

  (i) What is node A's clock offset with respect to the time at node B (you can ignore any processing delays at either node)?

  (ii) Is node A's clock going too slow or too fast?

  (iii) How should node A adjust its clock?

- (c) Two nodes A and B use RBS to receive periodic acoustic synchronization signals from a reference node. Node A's clock shows 10 s when it receives the last synchronization beacon, while node B's clock shows 15 s. Node A detects an event at time 15 s, while node B detects the same event at time 19.5 s. Assume that node A is 100 m away from the synchronization source and node B is 400 m away from the synchronization source. Which node detected the event sooner and by how much? Assume a signal speed of 300 m/s.

- (d) TOA requires that all the reference nodes and the receiver have precise synchronized clocks and the transmitted signals be labeled with time stamps. TDOA measurements remove the requirement of an accurate clock at the receiver. Assume that five reference nodes have known positions $(0,0), (-1,-1), (0,1), (3,1)$, and $(1,4)$ respectively. We choose $(0,0)$ as the reference sensor for differential time-delays which are defined as

$$t_{1r} = t_1 - t_r = \frac{r_{s1} - r_{s2}}{v}$$

where v is the velocity of propagation, r_{si} is the distance between the unknown node and the i th node. Further assume that $t_{12} = -1.4s, t_{13} = 0.4s, t_{14} = -1.6s$, and $t_{15} = -2.6s$
(a) Find the unknown location (x_t, y_t).
(b) Now assume that the propagation speed is known as 1.8 m/s. Find the unknown location (x_t, y_t).

Question 4: OMNeT++ and Synchronization (25 points)

Refer to the article **A Simulation Model of IEEE 802.1AS gPTP for Clock Synchronization in OMNeT++**, by Henning Puttnies, Peter Danielis, Enkhtuvshin Janchivnyambuu, and Dirk Timmermann, University of Rostock, Institute of Applied Microelectronics and Computer Engineering, Germany.

The article describes a simulation model of the gPTP protocol for time synchronization using OMNeT++ and the INET library. gPTP is part of the IEEE TSN standards. The simulation model is based on the IEEE 802.1AS specification for full-duplex Ethernet for a specific network topology and use case. Time synchronization and propagation delay measurements between time-aware systems are analyzed.

Links

The article can be found at the following link:

https://easychair.org/publications/open/Q4kL Link for the article

The OMNeT++ implementation can be found at:

https://gitlab.amd.e-technik.uni-rostock.de/peter.danielis/gptp-implementation/-/tree/master/IEEE8021AS Link for the the code

Reimplement the simulation and report the results and compare them with the results reported in the article.

Question 5: Coverage Control (30 Points)

1. (CTR/topology for connectivity:6 points) A network of wireless IOT devices is to be deployed uniformly in a (1,000 meters by 1,000 meters) area to collect data and to control the switching of a set of lights.
   (a) make the necessary assumptions and determine the minimum connectivity transmission range.

(b) explain network attribute that it is k-connected?

(c) draw the k-connectivity probability profile for the network.

what is the probability that the network is 1-connected,2-connected, and 7-connected?

2. (Topology for coverage:24 points)

(a) [4 pints] What is the difference between the detection optimal coverage and estimation optimal coverage?

(b)[20 points] In the class we studied one scenario of optimal sensor placement, as follows:

A generalization of the ILP problem is to minimize the network cost if different sensor nodes have different costs and coverage capabilities.

Sometimes, we may have other constraints such as the distance between any pair of sensor nodes should not be less than a certain min distance.

For example, in the scenario of placing different types of sensors, suppose that we have A types of sensors, each type with cost c_a and coverage distance $r_a, a = 1, \ldots, A$. Normally, a larger coverage range corresponds to a larger cost. Let D_a (i) denote the set of targets that can be covered by a type a sensor placed at site i, i.e.,

$$D_a(i) = \{j \mid d(i,j) \leq r_a\}, \quad i = 1, \ldots, I$$

where $d(i,j)$ is the Euclidean distance between a site i and a target j. Again, we use $x_i^a = 1$ to denote that a type a sensor been placed at site i and $x_i^a = 0$ otherwise. Furthermore, the coverage requirement is to cover each target with at least k sensors. The objective is to minimize the total sensor placement cost

$$\text{Minimize: } \sum_{i=1}^{I} \sum_{a=1}^{A} c_a x_i^a \tag{1}$$

Subject to:

$$\sum_{a=1}^{A} \sum_{j \in D_a(i)} x_i^a \geq k, \quad i = 1, \ldots, I \tag{2}$$

$$\sum_{a=1}^{A} x_i^a \leq 1, \quad i = 1, \ldots, I \tag{3}$$

Optimization Context

- The first constraint ensures that each target is covered by at least k sensors, and the second constraint is to ensure that each site can be occupied by at most one sensor.
- It is also possible to allow that some points are not covered by any sensor. This might be the case where we use grid approach to approximate area coverage.
- Hence, some other variants of sensor placement problems include
  - (a) maximizing the number of covered targets subject to a given number of sensors and
  - (b) minimizing the network cost subject to a minimum target coverage ratio. For directional coverage model, another objective is to optimize sensor orientational angles to maximize target coverage..

All these types of sensor placement problems are basically optimization problems and can be formulated as various mathematical programming problems.

Deliverables

You are asked to come up with a minimum cost sensor placement plan that covers a 500mx500m surveillance area.

- You have access to three types of omnidirectional sensors:
- Type S1 with a detection range of 100 meters,
- Type S2 with a detection rage of 70 meters.
- Type S3 with a detection range of 30 meters.
- The cost of type S1 is 300 units, S2 is 170 units, S3 is 65 units.
- You have access to unlimited supply of these sensors. The network is tasked with monitoring 17 targets. These targets are randomly and uniformly positioned within the boundaries of the surveillance area.

1. Device a function to distribute the 17 targets around the surveillance area.
2. Device either a genetic algorithm or a simulated annealing algorithm to compute an optimal node placement, using the model proposed above.