ECE9047: Laboratory 4

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Objective

This lab is about designing a wireless sensor network to perform a specific task within certain design constraints.

- Most of this lab is making design decisions, so there a lot of detailed quantitative analysis is not necessary.

The goal of this lab is the following:

> **Design a wireless sensor network to track an animal population and monitor environmental conditions in a given habitat.**

The sociology and biology departments of the *Brantford University of Teaching & Technology* (BUTT) would like to study the distribution and behaviour of a particularly strange breed of animal: undergraduate engineering students. They have noticed that these students tend to cluster in the gloomy basements of the Engineering building. The sociology and biology departments have commissioned you to design a WSN to monitor the area to help collect the following data:

- Undergraduate engineering students have notoriously poor personal hygiene. Is this because they are sensitive to moisture? Your WSN should provide **humidity sensors** over the region.
- Undergraduate engineering students are often nocturnal. Is this because they are sensitive to light? Your WSN should provide **light sensors** over the region.
- Where do the undergraduate engineering students congregate? Are they social or antisocial within their own habitat? Your WSN will attempt to roughly track population migration by having **pressure sensors** on the floor that are triggered when someone steps on them.

There are a few design constraints for this WSN. This sociology/biology research project isn't exactly approved by BUTT's research ethics board, so the WSN must be designed so that nobody notices it. This means the WSN cannot use very much of BUTT's infrastructure. In particular:

- Your WSN needs to provide its own wireless communication. It cannot use BUTT's campus WiFi network.
- Your WSN nodes can only use external power if that node is at an existing power outlet. You can't run an extension cord or rewire the power grid.
- Only one of the WSN nodes can connect to wired ethernet, because only one researcher is willing to give up their network ID for the connection. Only a node that is located at an existing ethernet outlet can use the ethernet. You can't run an ethernet cable across the floor. One node must be connected this way in order to transmit the WSN data to the relevant researchers.
- The sociology/biology researchers have little to no funding. Your WSN design has a **budget of $3000** for hardware (deployment cost is free — graduate students cost nothing!).
- Your network must be fully connected, of course.
- Your network should provide as much coverage as possible, within the cost constraints.
- Your network should have as long an operating lifespan as possible, within the cost constraints.

A list of available hardware, and a detailed scale map of the region is provided at the end of this lab manual.

Deliverables

You must submit your lab report online to the course website on OWL. Your lab report must include:

1. A statement of the problem:. You can reword the objective given above.

2. Describe the design philosophy of your network.

   - Is your network homogeneous or heterogeneous?
   - Will it be deployed with some structure or randomly (possibly a combination of both)?
   - What is the k-connectivity of the network, and are there any areas that are particularly sensitive to device failure in terms of connectivity?
   - What is the expected lifespan of the network? (i.e., One month? A semester? An academic year? 10 years?)
   - Is there a plan to replace failing nodes? (This depends on how well your network is connected — a poorly connected network probably requires replacements of key nodes if they fail.) A regular replacement plan should be included in the budget.

   You should discuss what you considered when making these design decisions, and justify your final network design.

3. Describe your philosophy and metrics for sensor coverage. Each of the three sensors (light, humidity, pressure) technically only measures data at a single point, so what do you consider is an appropriate sensing radius for each? Given that design decision, what is the k-coverage of your network for each of the three sensor types? (Each sensor will have a different k-coverage if each has a different sensing radius, and/or if a heterogeneous network uses a different combination of sensors on various nodes.)

4. Describe the construction of the nodes in your network, based on which hardware components are used (the length of this section depends on the network - obviously a homogeneous network has only one node to describe, while a highly heterogeneous may have many different nodes).

5. Describe the deployment of the network. Feel free to make any assumptions you wish about which areas might be higher- or lower-priority for sensing.

   - Provide one or more accurate plots of the network, showing the precise location of each node (and the type of each node, if you have a heterogeneous network).
   - It will be assumed that all nodes are mounted on the floor, unless otherwise indicated. Wall-mounting and ceiling-mounting are allowed, and should be identified as such in the diagram of your network (either label them, or use a different symbol/color, etc.).
   - You should discuss why you use floor-, wall-, or ceiling-mounting in the description of network deployment.
   - You should also include a plot of the communication channels, and sensor coverage. (It may be possible to combine all of these into one plot as long as it is still easy to read.)

6. Describe the operating procedure for your network.

   - When will sensor data be acquired? At regular intervals (if so, specify the time interval), or as interrupts (i.e. whenever sensor state changes)? This may be different for different sensors and/or types of nodes.
   - How is interference between the sensors prevented? For example, you can't measure light and pressure data simultaneously at the same node, because a positive pressure sensor input means someone is standing on the node, quite possibly blocking the light. Either light measurements are acquired only when the pressure sensor is not triggered, or light sensors and pressure sensors are mounted in physically different nodes.
   - What is the actual data acquired? Are quantitative sensor measurements recorded (humidity sensor reads $36\,\%\mathrm{RH}$, pressure sensor reads weight of $50\,\mathrm{N}$), or does the WSN just record a timestamp for when a sensor measurement passes some threshold, or both?

- Finally, how does the acquired data help address the original problem: determining whether there is a correlation between humidity, light, and number of engineering students present?

7. Discuss the strengths/weaknesses of your network.
   - How easy is it for a target to pass through the network without triggering a pressure sensor?
   - Where are the weak-points or choke-points for communication? Is any part of the network particularly susceptible to becoming disconnected if a few key nodes fail?
   - Because the environment area is an irregular shape, Voronoi tessellation and Delaunay triangulation are probably not particularly useful. You can still use them if you wish, but you would need to adjust the cost functions (for maximal breach paths and maximal support paths) to keep the paths from going "out of bounds".
8. Finally, provide the budget for the WSN (remember, you have a maximum of **$3000**). A list or a table is sufficient, unless you really like writing everything in paragraph form. (If you designed a completely homogeneous network then really you just need one line showing the cost of the node times the number of nodes.)

Your report should not be excessively long. Probably two to five pages is sufficient, depending on how many figures you have (and how large they are).

There are a lot of different choices you can make when designing the WSN, so please make sure everything is consistent. For example: whatever your proposed replacement plan and expected lifespan is should roughly agree with the power supplies for your nodes and the operating. Precise calculations are not required, but suggesting that your WSN will last 10 years without any replacement, while having all sensor nodes constantly measuring and transmitting data, and having all of this data relayed through a single node with the lowest capacity battery is obviously not going to work.

Grading Scheme

Your report will be graded by the following scheme.

5% **Statement of the Problem**. Marks awarded based on how clearly the problem is stated.

10% **Design Philosophy**. Marks awarded based on clarity and justification of your decision making process, and on whether you addressed sufficient aspects of WSN design.

10% **Description of Sensor Metrics and Coverage**. Marks awarded based on clarity and justification of your decision making process, and on whether you addressed sufficient aspects of sensors.

10% **Operating Procedure**. Marks awarded based on clarity and justification of the operating procedure, and on how well the purpose of the WSN is realized by your design.

10% **Critical Analysis of Strengths/Weaknesses**. Marks awarded based on clarity and details of the analysis of your network.

10% **Figures**. Marks awarded for providing accurate diagrams of the WSN showing all requested information.

30% **Technical Information**. This includes the description of the node construction, and analysis like k-connectivity and k-coverage. Marks awarded for correctness, and for how well WSN meets the design goals.

5% **Budget**. Marks awarded based on whether you calculated the budget correctly.

10% **Writing Quality**. Marks awarded based on the extent to which your report is written coherently, in paragraph form, with complete sentences. Correct spelling and grammar are also included. Marks may also be deducted if the report is exhaustively long.

Resources

To keep things simple, only a few options for constructing WSN nodes are given here.

Base: All nodes must use a generic microcontroller as their basic component. This microcontroller has a few timers, a 4-channel analog-to-digital converter, and a few general purpose input/output ports. The microcontroller has enough memory for programs and some data storage, but not enough to store all the collected sensor data collected over an extended period of time (a few days, say). Communicating collected sensor data outside the WSN is a priority.

Light Sensor: A generic light sensor (photodiode or photoresistor) that can connect to the microcontroller analog-to-digital converter.

Humidity Sensor: A generic humidity sensor (capacitive or resistive) that can connect to the microcontroller analog-to-digital converter.

Pressure Sensor: A flat panel, measuring $10\,\mathrm{cm} \times 10\,\mathrm{cm}$, that measures applied force (weight). This is attached to the microcontroller analog-to-digital converter by a short cable.

The analog-to-digital converter on the microcontroller has more than three channels, so all sensors can be attached to the same node without any technical problems. You may assume the power consumed by these sensors is negligible. The major use of power by these nodes will be transmitting data wirelessly, so we will consider that as the only significant use of power.

All available batteries are listed based on the approximate number of transmission packets (assuming each packet is only a few bytes in size) that can be sent before the battery is depleted.

Low-Capacity Battery: The available low-capacity battery can provide an estimate of 2000 short-range wireless transmissions.

Medium-Capacity Battery: The available low-capacity battery can provide an estimate of 10 000 short-range wireless transmissions.

High-Capacity Battery: The available high-capacity battery can provide an estimate of 50 000 short-range wireless transmissions.

Power Converter: An AC/DC power converter brick is needed if the node will plug into a wall outlet. The wall outlet provides essentially unlimited wireless transmissions.

Each node uses a wireless transmission to send sensor measurements to a connected node in the network, and *also* must use a wireless transmission to relay another node's transmission. Which nodes need to relay the most information is probably the key aspect to consider when deciding which power supply to use.

We have access to two types of wireless hardware: Zigbee and Z-wave. You may combine both protocols into your network if you wish, but of course Zigbee can only communicate with other Zigbee nodes, and Z-wave can only communicate with other Z-wave nodes. You can put both Zigbee and Z-wave hardware on a single microcontroller if you want a node to be able to use both protocols.

- For simplicity, we will assume both protocols use the same power consumption for a short-range wireless transmission.
- Both wireless signals can bounce around corners, but the signals cannot pass through thick walls (shaded grey in the map).

It is also possible to make sub-networks using either or both protocols — if you wish, your WSN can consist of three independent Zigbee networks — as long as there is a communications path from every node to the ethernet-enabled node that connects to the outside world. If you use multiple independent networks, this means that at least one node must have multiple transmission chips so it can communicate on multiple networks.

Ethernet Port: One node in your network needs an ethernet port to communicate with the outside world.

Zigbee short-range wireless transmission is limited to $10\,\mathrm{m}$. A power-boosted long-range wireless transmission can reach $90\,\mathrm{m}$, but this uses $20\times$ the normal power consumption.

Zigbee Coordinator: Each Zigbee network must have one node with the Zigbee Coordinator (ZC) chip. A ZC node can communicate directly with other nodes, and can also relay information.

Zigbee Router: A Zigbee router (ZR) can communicate directly with other nodes, and can also relay information.

Zigbee End Device: A Zigbee end device (ZED) can only communicate with other nodes directly. It cannot relay information.

There is no limit to the number of hops in a Zigbee network.

Z-wave short-wave wireless transmission is limited to $30\,\mathrm{m}$ A power-boosted long-range wireless transmission can reach $90\,\mathrm{m}$, but this uses $20\times$ the normal power consumption.

Z-wave Transmitter: All nodes in a Z-wave network use the same hardware. This can communicate directly with other nodes, and also relay information. However the relay path is limited to a maximum of 4 hops.

A Z-wave network requires a control node, but that is software configured and assigned during network deployment — all nodes use the same hardware.

The cost of these components is given below.

Category	Description	Cost
Base	Microcontroller	$10
Sensor	Light Sensor	$2
	Humidity Sensor	$2
	Pressure Sensor	$2
Power Source	Low-Capacity Battery	$5
	Medium-Capacity Battery	$15
	High-Capacity Battery	$25
	Power Converter	$5
Communications	Zigbee Controller (ZC)	$25
	Zigbee Router (ZR)	$10
	Zigbee End Device (ZED)	$5
	Z-Wave Transmitter	$20
	Ethernet Port	$5

The cheapest functional node therefore costs $22 (base, one sensor, a low-capacity battery, and a ZED transmitter).

Note: It is not necessary for each node to use all of its hardware. For example, if you really like homogeneous networks you can give every node a ZC transmitter, ethernet ports, batteries, and power converters. The role of each node can then be self-configured during deployment: only one node will actually act as the ZC, the rest will act as ZRs; only one node will actually use the ethernet port; and only nodes near power outlets can use the power converter (and consequently won't use the battery). Probably this isn't a good way to spend money, but it is still a valid design choice.

Sensing Environment

A map of the BUTT engineering basement is given below. Each grid square is $5\,\mathrm{m} \times 5\,\mathrm{m}$. Copies of this map are provided in PDF, SVG, and PNG form — you should probably use these to draw your network.