NUS

National University of Singapore

School of Computing

CS4222/CS5422 Wireless Networking

AY20/21 Semester 2

Final Assignment Report

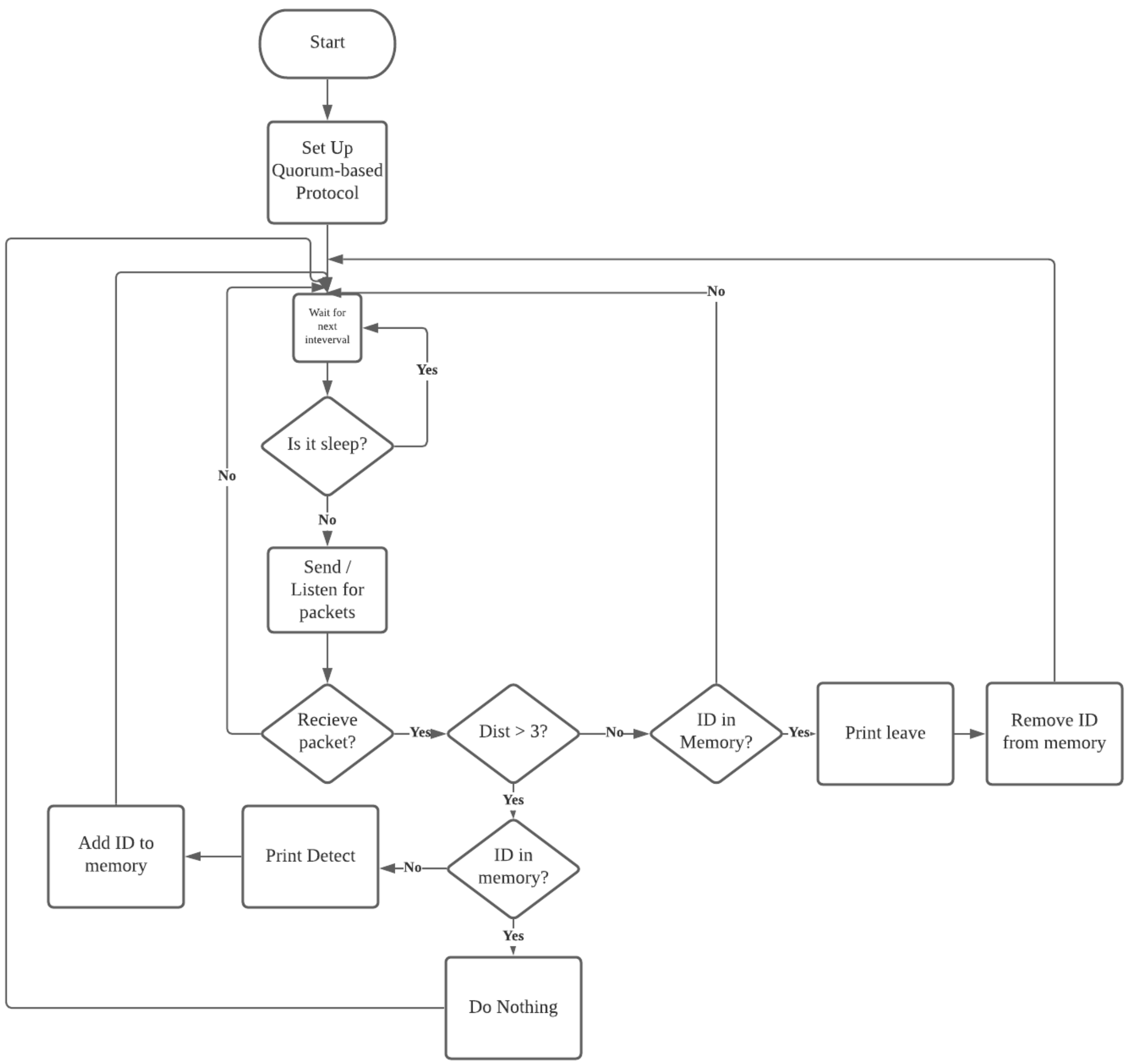
Team x

Team Members	Matriculation No.	Email

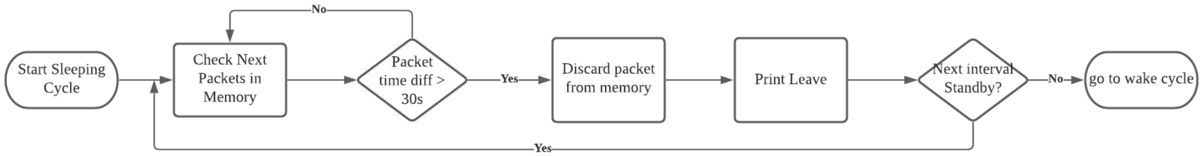
Overview

The main idea of the project is to run the Quorum-based protocol to set the sleep or discovery time for each node using a $n \times n$ grid. There are two main states in this, sleep and discovery. For each discovery period, the node would send and listen packets from other possible nodes. If it receives a packet, the node would check the sender's ID and the estimated distance of the nodes using RSSI. If the distance is less than 3m, the SensorTag will print "DETECT" and save the sender's ID and the timestamp upon receiving the packet into memory. If the distance is more than 3m, the SensorTag will print "LEAVE" and discard that sender's ID from memory.

Below shows the flow chart of the node's program.



During the sleeping state, the radio is off and the node will do an internal check of sender IDs. If the sender ID is in the memory for more than 30 seconds, the node would discard the record from its memory and print “LEAVE”. This can be seen as illustrated by the flowchart below



Assumptions

These are the assumptions made when conducting experiments:

- There are less than 10 people around each time
- Close proximity is only considered when there is a line of sight between two nodes
- Trace-to-gether should not consider tags from another room even though they are within 3 meter apart

Limitations of the experiments

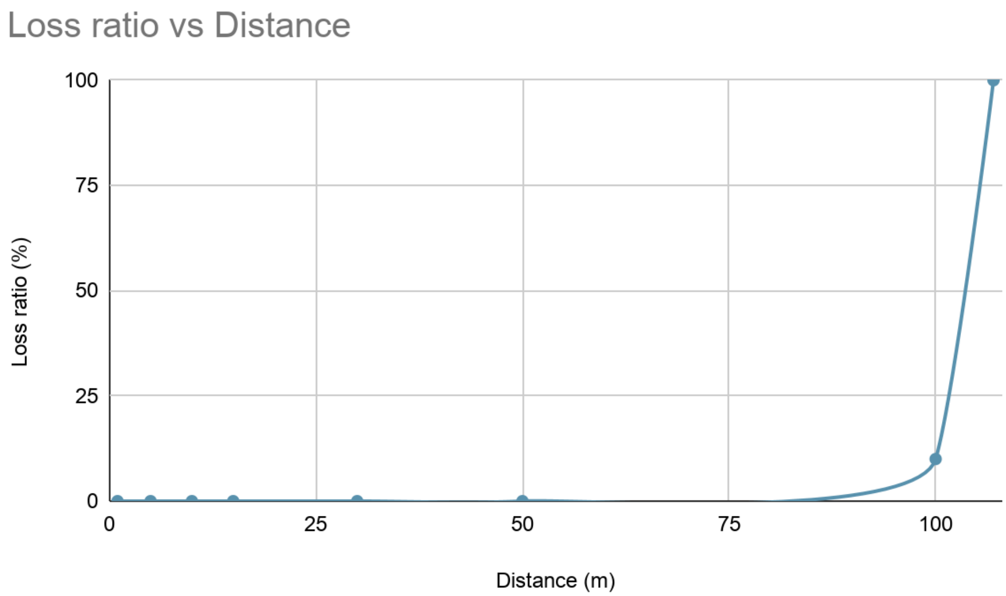
- Only 3 nodes available to test
- Substitute No Wifi Zone to Weak Wifi Zone

Components

Packets Sending and MAC

Our team made use of the ContikiMac protocol to send packets from node to nodes. As seen by assignment 3, it can be determined that the rate of packet loss in relation with distance is not that significant especially if the distance is less than 50m.

The following shows the data collected from assignment 3.



Assignment 3: Graph of loss ratio against distance

Based on the graph, we can determine that the distance of 3m is not affected by packet loss ratio.

The only main factor that affects the rate of packet loss is walls as obstacles between the two nodes. However, due to the assumption that nodes that are in different rooms, separated by walls, are not considered to be in close proximity regardless of distance, thus packet loss to these nodes are negligible.

Discovery Protocol - Quorum-based Protocol

The discovery protocol implemented in the program is the Quorum-based protocol. This protocol is chosen due to its deterministic and low power approach in exchanging packets.

The protocol makes use of a $n \times n$ grid where each node randomly picks a row and a column. The node iterates through the grid and it starts the discovery phase when it is in the chosen row or column. Any other node that is in the discovery phase would be able to detect each other. During discovery time, the node would send packets and listen at the same time.

As such, one of the main problems is to determine the right N_SIZE such that there would not be a loss of accuracy in detect time and leave time.

Since contact tracing is a time sensitive operation where nodes have to exchange the data as they pass by each other, using a small N_SIZE would achieve a higher frequency of data exchanging.

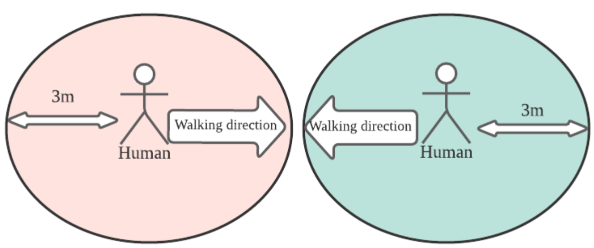
With the smaller N_SIZE, this would increase the duty cycle which implies more power is consumed. Thus, it is necessary to choose the right N_SIZE to maintain accuracy in data collection and achieve low power consumption.

An experiment is conducted to determine the best N_SIZE. For each N_SIZE, 10 sets of 20 time intervals of receiving packets have been collected. Collection was done this way due to the randomness of chosen rows and columns in the discovery protocol. After collection, the timings are averaged and displayed below.

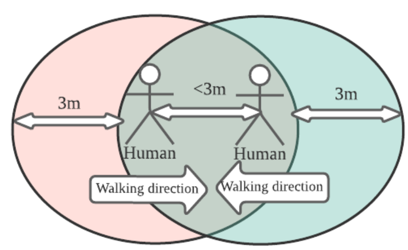
Between two nodes - Time each slot: 0.0625, Best worst and Average time

N_Size	Worst Time	Best Time	Average time
6	1.875	0.053	0.55625
10	5.57	0.055	1.23083
11	6.875	0.055	2.176565
12	8.25	0.037	3.123785
14	11.375	0.055	4.49538

The interval chosen is based on the consideration of average human walking speed. The interval upper limit and lower limit is based on the time calculated when two people enter a 3m range on opposite sides of each other and how long it takes for them to walk past each other before exiting the 3m range.



Coming into close proximity



Into close proximity

Based on the data collected by HealthLine, the average human walking speed is 3.5 miles per hour[1]. By calculation, this means that the average human walking speed is 1.56 m/s. With this, the time for an average human to walk 3m is **1.92s.** Thus, the chosen N_SIZE's average time cannot be more than 2 seconds.

1 [1]E. Cronkleton, "Average Walking Speed: Pace, and Comparisons by Age and Sex", *Healthline*, 2019. [Online]. Available: https://www.healthline.com/health/exercise-fitness/average-walking-speed. [Accessed: 19- Apr-2021].

This leads to the highest value of N_SIZE we can consider is size 10 whose average time is 1.23s.

The period would be n^2 slots with the active slots being 2n - 1. The chosen N_SIZE would yield the following parameters.

N_SIZE	10
Period (slots)	100
Active slots	19
Duty Cycle (%)	0.19

RSSI Threshold value for DETECT

RSSI is used mainly as a way to record the distance between two nodes. In order to figure out the right threshold to count as 3m, an experiment was done to collect data on the distance against RSSI value detected without an obstacle.

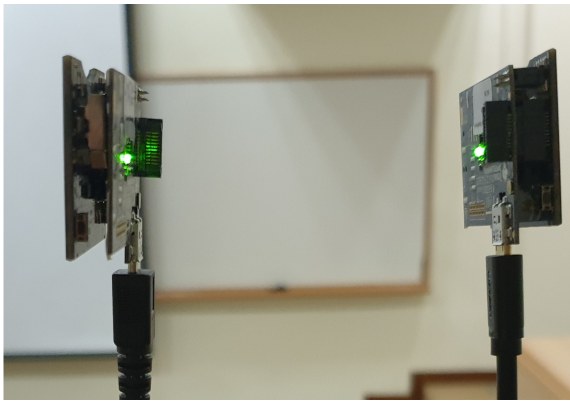
There are several factors that affects the RSSI data that is being collected between two sensor nodes, these include

- Orientation of nodes
- Environment
- Number of nodes in the area
- Movement of nodes

In order to choose the right RSSI value that would represent 3m, we have to take these other factors into account. As such, our team did several experiments in order to estimate the right value for our RSSI threshold. Do note that our team did not consider obstacles such as walls between rooms due to our assumptions.

Orientation of nodes

There are 2 orientations considered as shown below.



Worst case Scenario Best case scenario

For the image on the left, both sensors are facing away from each other. This gives the worst RSSI results and is labeled the worst case scenario.

For the image on the right, both sensors are facing each other. This gives the best RSSI results and is labeled the best case scenario.

In consideration of the orientation of the nodes, RSSI data is collected. At each distance, 10 RSSI values of both worst and best case are measured. The final value is then calculated by taking the average of the overall values.

Between two nodes - WIFI zone

Distance (m)	Worst case Avg (RSSI)	Best Case Avg (RSSI)	Average (RSSI)
1	49.3	41.7	45.5
2	56.5	43.2	49.85
3	66.8	48.1	57.45
4	64.7	51.9	58.3
5	72.5	57	64.75

Based on the data, to recognise 3m within WIFI zone, the threshold is decided to be RSSI value of 57.

Indubitably, different threshold values are considered when obstacles are around. For example, a threshold value for detection averages around 70-90, depending on the amount of obstacles between the two nodes. However, this threshold value drops down to an average of 57 if there is a clear Line-of-Sight between the two nodes.

External factors

The environment and the presence of other nodes was considered to affect the RSSI values. An experiment is conducted with the same parameters as above but in a different environment.

3 Nodes - WIFI Zone

```
Start clock 24 ticks, timestamp   0.187
       0 DETECT 4467
Received packet from node 4467 with sequence number 31 and timestamp   4.132 RSSI: -51
       0 DETECT 2920
Received packet from node 2920 with sequence number 7 and timestamp   2.070 RSSI: -53
Received packet from node 4467 with sequence number 32 and timestamp   4.187 RSSI: -52
Received packet from node 2920 with sequence number 8 and timestamp   2.125 RSSI: -52
Received packet from node 4467 with sequence number 33 and timestamp   4.757 RSSI: -50
Received packet from node 2920 with sequence number 9 and timestamp   2.695 RSSI: -52
Received packet from node 4467 with sequence number 34 and timestamp   4.812 RSSI: -49
Received packet from node 2920 with sequence number 18 and timestamp   4.687 RSSI: -42
Received packet from node 2920 with sequence number 19 and timestamp   4.687 RSSI: -41
Received packet from node 4467 with sequence number 50 and timestamp   6.812 RSSI: -46
Received packet from node 4467 with sequence number 51 and timestamp   6.812 RSSI: -46
Received packet from node 2920 with sequence number 46 and timestamp   8.375 RSSI: -41
Received packet from node 4467 with sequence number 71 and timestamp  11.007 RSSI: -45
Received packet from node 2920 with sequence number 47 and timestamp   8.945 RSSI: -41
Received packet from node 4467 with sequence number 72 and timestamp  11.062 RSSI: -45
Received packet from node 2920 with sequence number 56 and timestamp  10.937 RSSI: -40
Received packet from node 2920 with sequence number 57 and timestamp  10.937 RSSI: -41
Received packet from node 4467 with sequence number 88 and timestamp  13.062 RSSI: -43
Received packet from node 4467 with sequence number 89 and timestamp  13.062 RSSI: -43
Received packet from node 2920 with sequence number 84 and timestamp  14.625 RSSI: -41
Received packet from node 4467 with sequence number 109 and timestamp  17.257 RSSI: -44
Received packet from node 2920 with sequence number 85 and timestamp  15.195 RSSI: -40
Received packet from node 4467 with sequence number 110 and timestamp  17.312 RSSI: -44
Received packet from node 2920 with sequence number 94 and timestamp  17.187 RSSI: -42
Received packet from node 2920 with sequence number 95 and timestamp  17.187 RSSI: -41
Received packet from node 4467 with sequence number 126 and timestamp  19.312 RSSI: -45
Received packet from node 4467 with sequence number 127 and timestamp  19.312 RSSI: -45
Received packet from node 2920 with sequence number 122 and timestamp  20.875 RSSI: -43
Received packet from node 2920 with sequence number 123 and timestamp  21.445 RSSI: -44
Received packet from node 2920 with sequence number 132 and timestamp  23.437 RSSI: -40
Received packet from node 2920 with sequence number 133 and timestamp  23.437 RSSI: -40
Received packet from node 2920 with sequence number 160 and timestamp  27.125 RSSI: -41
Received packet from node 2920 with sequence number 161 and timestamp  27.695 RSSI: -41
Received packet from node 2920 with sequence number 170 and timestamp  29.687 RSSI: -41
Received packet from node 2920 with sequence number 171 and timestamp  29.687 RSSI: -42
Received packet from node 2920 with sequence number 198 and timestamp  33.375 RSSI: -42
Received packet from node 2920 with sequence number 199 and timestamp  33.945 RSSI: -41
Received packet from node 2920 with sequence number 208 and timestamp  35.937 RSSI: -44
Received packet from node 2920 with sequence number 209 and timestamp  35.937 RSSI: -44
Received packet from node 2920 with sequence number 236 and timestamp  39.625 RSSI: -43
Received packet from node 2920 with sequence number 237 and timestamp  40.195 RSSI: -43
Received packet from node 2920 with sequence number 246 and timestamp  42.187 RSSI: -42
Received packet from node 2920 with sequence number 247 and timestamp  42.187 RSSI: -42
```

The final result of the experiment shows that having more nodes in the vicinity and being in the weak WIFI zone does not affect the RSSI enough to consider having different thresholds in different environments.

Program Algorithm

Each time a node receives a packet from another node, it would verify if the packet is valid before storing the value into the memory. This is implemented using an array of size 10 since there is an assumption that at least 10 people would be around. For each packet value, the memory would store its ID and timestamp in a struct as shown below. The leave counter is initialised to 0.

```
typedef struct {
  unsigned long node_id;
  unsigned long timestamp;
  unsigned int leaveCounter;
} node;
```

When an incoming packet is determined to be sent from a node that is outside of 3m and it exists in the array, it will increase the leave counter by 1. Once the leave counter reaches the max of 3, the program will deem the node left, print out “LEAVE” and remove the node from the array.

The reason for this is for the program to ensure that the node has left the area since RSSI can be quite unstable, the receiving RSSI might be marked as left even though the node might still be in the vicinity within 3m. To counter this, the program would only count a node as left if it received the RSSI value above the threshold 3 times.

When an incoming packet is determined to be sent from a node that is below 3m, it would take an $O(n)$ lookup in its memory to find if it has a preexisting record of this node in its memory. If it has an existing record, the program will update its timestamp with the new timestamp. If it's a brand new node, the program will create a new record in its memory and print out “DETECT”.

Power and Energy Consumption

Discovery Protocol

The team decided on Quorum-based protocol over other protocols such as birthday protocol. The idea is that since the sensor tag is supposed to run a discovery algorithm majority of the time, the power consumption should be minimised for this algorithm. In order to do so, using similar parameters and with the consideration that the time between each slot was to be around 1.92s due to the average human walking speed, we limited both protocol’s parameters as shown in the table below and calculated the average energy consumption based on Cooja. We need the interval time to be less than 1.92s so as to ensure high accuracy in detecting and leaving of nodes.

Protocol	Birthday Protocol Consumption	Quorum-based Protocol
Parameters	WAKE_TIME = 0.08ms SLEEP_SLOT = 0.1ms SLEEP_CYCLE = 4	N_SIZE = 10
Accumulated energy Consumption after 50s (J)	1956822	1955728

Other parameters that were tried and tested includes:

Birthday Protocol Parameters	Mean Interval	Duty Cycle
WAKE_TIME = 0.1s SLEEP_SLOT = 0.1s SLEEP_CYCLE = 9	3.64	0.1
WAKE_TIME = 0.1s SLEEP_SLOT = 0.125s SLEEP_CYCLE = 9	6.77	0.0816
WAKE_TIME = 0.1s SLEEP_SLOT = 0.1s SLEEP_CYCLE = 4	0.79	0.2
WAKE_TIME = 0.08s SLEEP_SLOT = 0.1s SLEEP_CYCLE = 4	1.31	0.167
WAKE_TIME = 0.05s SLEEP_SLOT = 0.1s SLEEP_CYCLE = 4	2.50	0.111

From the results gathered, only parameters with results of a mean interval that is lesser than 1.92s were considered. From there, optimisation was done by ensuring lower power consumption and in this case, a WAKE_TIME of 0.08s had lower power consumption as compared to a WAKE_TIME of 0.1s and hence it was chosen.

N_SIZE for Quorum-based protocol

Increasing the N_SIZE would imply an increase in power consumption. This can be seen in the previous experiment where an increase in N_SIZE would result in an decrease in duty cycle. The higher the rate of duty cycle, the more energy the SensorTag would consume. However, since our choice of N_SIZE is restricted further based on the average walking speed of humans as deduced previously, the lowest possible N_SIZE would be 10 which yields an average power consumption of around 1955728 Joules and a duty cycle of around 19%

Choice of protocol

By running simulations using Cooja, the Powertrace log is printed out every 5seconds. An average from 5 to 55 seconds of simulation is calculated and the results are shown below.

Birthday

```
00:55.544      ID:2     7044 P 2.0 10 116113 1686820 7041 348639 0 0 10222 153331 734 37496 0 0 (radio 19.72% / 23.37% tx 0.39% / 0.44% listen 19.33% / 22.92%)
00:55.690      ID:1     7044 P 1.0 10 109750 1693183 7039 348639 0 0 9916 153637 733 37496 0 0 (radio 19.72% / 23.37% tx 0.39% / 0.44% listen 19.33% / 22.92%)
```

Quorum-based

```
00:55.545      ID:2     7044 P 2.0 10 144273 1658660 9815 342166 0 0 14410 149427 989 34299 0 0 (radio 19.52% / 21.53% tx 0.54% / 0.60% listen 18.97% / 20.93%)
00:55.691      ID:1     7044 P 1.0 10 148211 1654722 9765 342147 0 0 14789 149048 982 34295 0 0 (radio 19.51% / 21.53% tx 0.54% / 0.59% listen 18.97% / 20.93%)
```

Protocol	Average Radio Usage (Node 1)	Average Radio Usage (Node 2)	Average CPU Usage energy consumption per 5 seconds (Node 1)	Average CPU Usage energy consumption per 5 seconds (Node 2)
Birthday protocol	19.9%	19.9%	195 682	195 682
Quorum-based protocol	20.146%	20.146%	195 573	195 579

Hence, a Quorum-based protocol is chosen due to the slightly lower energy consumption which can lead to a huge difference if the SensorTag is to be run for a long period of time.

Summary and Discussion

Based on the above experimentation, although it is well known about factors affecting certain parameters, some of our experiments did not manage to show a substantial relationship between the factor and the parameters.

RSSI

It is found that RSSI can be affected by the surrounding environment as well as the surrounding nodes, wifi and other radio disturbances. As such, our team conducted an experiment to find out the relationship between the environment factor and the RSSI value. We tested the collection for RSSI value in 3 different scenarios.

- Wifi Zone
- No Wifi Zone
- More than 2 surrounding nodes.

However, our results showed insignificant difference in any of the 3 scenarios.

Another factor that shows a significant amount of relation with the RSSI value other than distance is obstacles in the surrounding area. Our team did not consider walls between rooms as obstacles but surrounding objects that possibly affects RSSI value. As such, the RSSI threshold values are offset in consideration of the possibility of small obstacles between SensorTags.

Power and accuracy tradeoff

During the choice of our parameters, our team's main concern is to find a good trade off between accuracy and power consumption. Since the choice of our time interval slot is limited to 1.92s, the choice of parameters start from this constraint. A smaller N_SIZE results in more consistent and smaller packet intervals which in turn increases the accuracy as the detection and leaving of nodes will be recognized more quickly. This comes at the expense of a higher radio usage and higher energy consumption. The inverse is also true for a larger N_SIZE. Hence, in order to establish a "middle-ground", an average walking speed was used to calculate the average time humans take to travel 3m. From there, compensation between N_SIZE and packet intervals was done whereby N_SIZE is kept to the smallest possible value while maintaining a packet interval that is less than 1.92s.

Detection and leaving algorithm

One of the challenges is to come up with a detection algorithm that is accurate and fast. Considering the limitations that are set, detection should be done immediately while leaving can be delayed. That makes detection straight forward as the first packet can be used to detect. However, to justify a node has left is challenging due to the RSSI values not being consistent. Other strategies such as receiving consecutive increasing RSSI values to determine a node has left can be unreliable. The RSSI values can be inaccurate due to obstacles and inconsistent human movement. The SensorTag has insufficient sensors to be able to detect these factors. In the end, just setting a threshold and receiving RSSI values to be more than the threshold more than 3 times is sufficient to detect that a node has left.

Conclusion

In conclusion, the team made use of the average walking human speed 1.92 as the base constraint and picked protocol parameters based on the best power saving constraint by the base constraint. The team made use of the Quorum based protocol with an N_SIZE of 10 as well as the RSSI threshold of 57 as an indicator of 3m. All protocols and parameters are chosen with power consumption and accuracy in mind.