GROUP ASSIGNMENT COVER SHEET

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Unit name and code	FIT3143 - Parallel computing	
Title of assignment	Assignment 2- SEISMIC READINGS FOR EARTHQUAKE DETECTION IN A DISTRIBUTED WIRELESS SENSOR NETWORK (WSN)	
Lecturer/tutor	Dr. Vishnu Monn	
Tutorial day and time	Wednesday 2-4PM	**Campus:** Malaysian
Is this an authorised group assignment?	√ **Yes**	
Has any part of this assignment been previously submitted as part of another unit/course?	√ **No**	
Due Date: 18/10/2022		**Date submitted: 18/10/2022**

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FIT3143 Semester 2, 2022
Assignment 2 - Report

Team Name (or Number): <u>Team 15</u>

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**Your contribution details include the report, code, or both.*

Note: Please refer to Assignment specifications, FAQ and marking guidelines for details to be included in the following sections of this report.

Include the word count here (for Sections A to C): **1568** (Excluding Figures, Flowchart, Results, Tables and Instructions)

A. Methodology

In this report, we will be documenting about the simulation of a wireless sensor network (WSN) of interconnected seismic sensors.

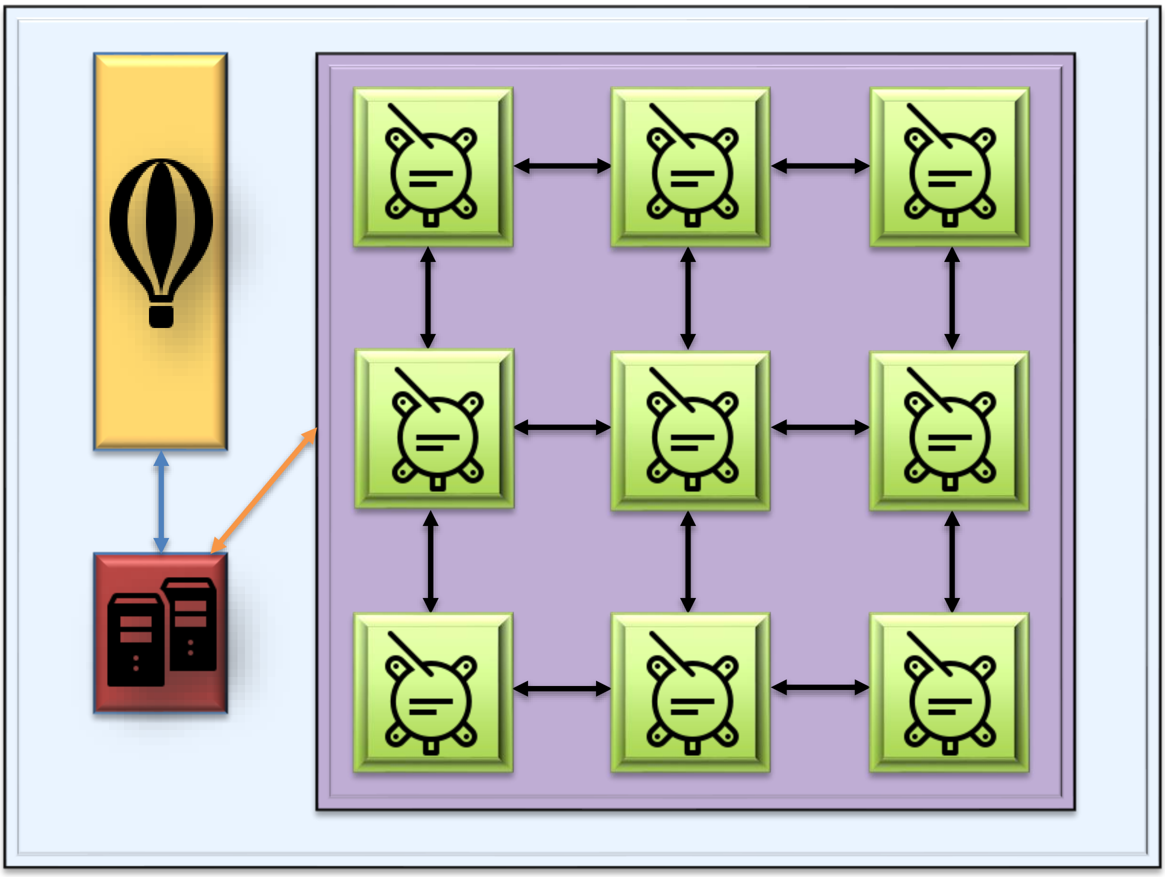

Figure 1.1: An overview of the architecture and design of the WSN, alongside with a balloon seismic sensor. For reference, the illustration below consists of **9** seafloor seismic sensors positioned within a **3**×**3** Cartesian grid layout where all of them could communicate with each other (black bidirectional arrows) as well as the base station (orange bidirectional arrows).

A 2D virtual topology is created using MPI Cartesian functions where the seismic nodes (*slaves*) are placed and sends a series of messages to the base station (*master*) which also performs the computations.

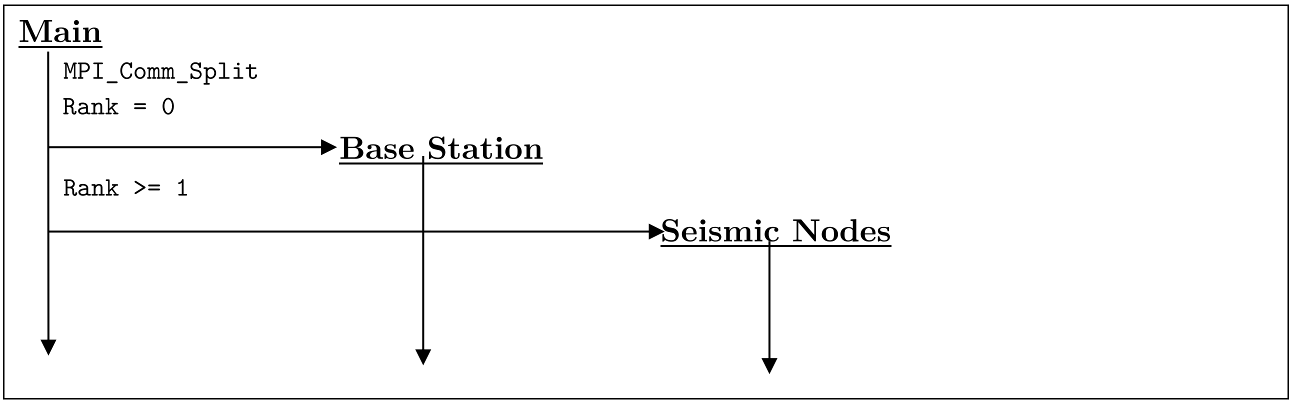

Figure 1.2: Splitting of MPI Communicators

A total of 3 sections will be divided for the code, namely the seafloor seismic sensor nodes, the balloon seismic sensor and the base station, which is designated into subtasks (a), (b) and (c) respectively.

a) Seafloor Seismic Sensor Nodes

To simulate the seafloor seismic sensor nodes, the '`node_log`' custom datatype is initialized, where it contains the node rank, its respective row and column, latitude, longitude and magnitude. Next, the 2D topology is created with no re-orderings and no wrap-around. The individual node's coordinates expressed in the cartesian form and its cartesian rank will then be retrieved upon creation where the **4** adjacent nodes will be saved into up, down, left and right variables respectively.

Now that the initialization is complete, we will now move on to the simulation process. In each simulation (i.e., iteration), the whole process will run for precisely 1 second, where it includes:

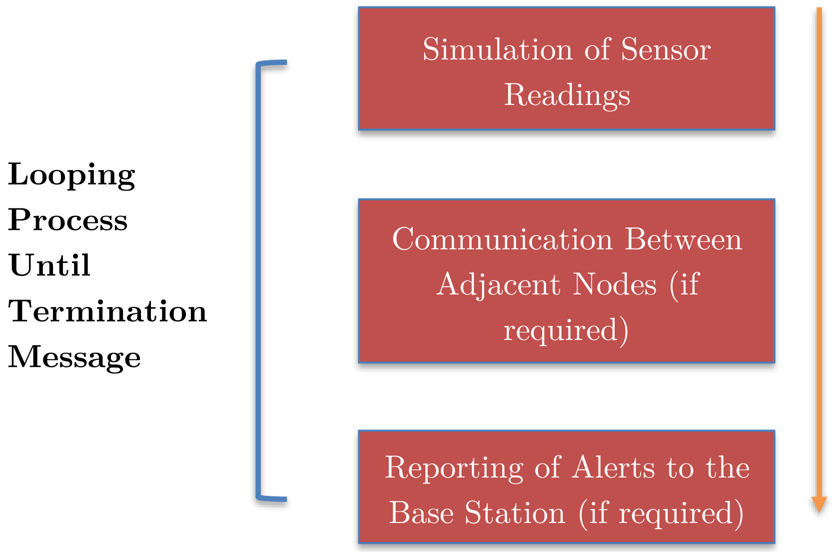

Figure 1.3: Process Flow for each Seismic Node

In any case, the process will only be terminated if a termination message is received from the base station.

Simulation of sensor readings

To achieve this, a random seed will first be assigned to the time at which the iteration starts, multiplied with the node's cartesian rank + 1 to increase the randomness whereas the latitude and longitude will be determined by its coordinates within the topology, in which each row and column coordinate represents an offset of 1 degree of latitude and longitude respectively, followed by a random value that is within a range of 0 to 0.9.

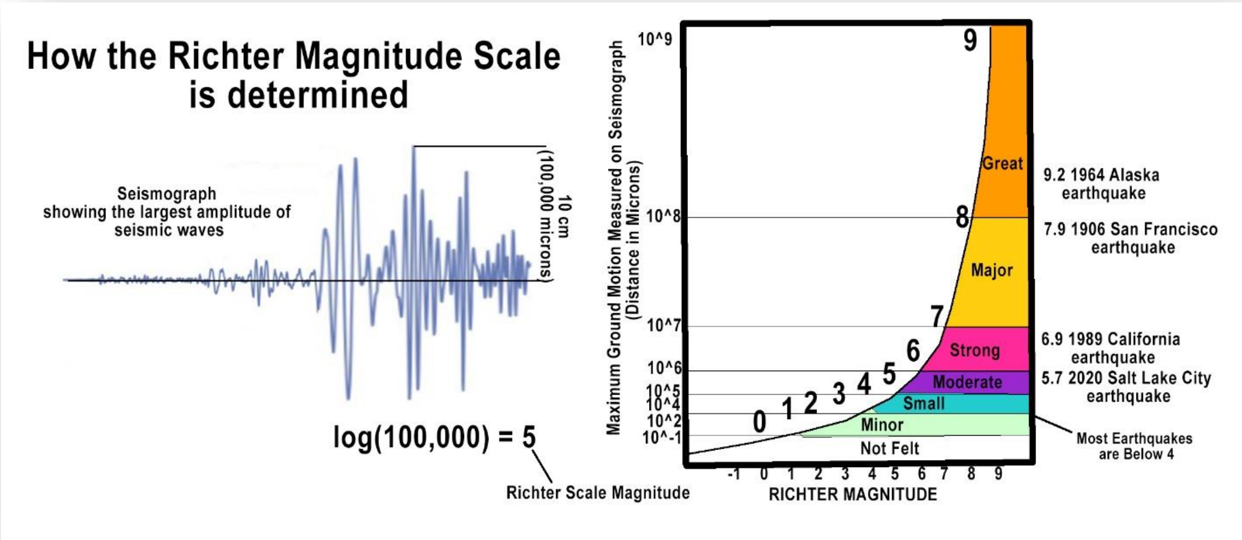

Figure 1.4: Richter Magnitude Scale

To simulate the magnitude values, in accordance with the frequency of earthquakes and their strengths, the greater the magnitude on the **Richter Magnitude Scale**, the less frequent it is. Here we have came up with a method where we've utilized a normal distribution function where we can specify the strength (chances of hitting the median value) and the target value (median value). In this assignment, the target value is set to **0.2**, whereas the strength is set to **1**. This ensures that the frequency of earthquakes with more than or less than a magnitude of **1.6** will occur less frequently, with decreasing frequency as the difference grows between the median value. The generated value will be within a value of **0** to **1** and multiplied by **8** to produce the final magnitude value. The depth value is also generated similarly to the magnitudes, but the final result will be multiplied by **200** instead.

Communication between adjacent nodes

Once the individual nodes have their sensor readings simulated, a variable that contains a Boolean called '`trigger`' is created and is used to identify whether a node's magnitude exceeds the magnitude threshold. This trigger is sent and received, to and from its adjacent nodes in an asynchronous manner and will be saved in `received_trigger` array.

Trigger itself also serves as a request notification, where if any of the values in the array were received as a true value, it indicates that at least one of its adjacent nodes is exceeding the magnitude threshold and requires that particular node to send its information. Thus, the sending of information here is only triggered if its adjacent nodes requests for it, through their trigger values.

For all nodes, an array, `receive_data` will be initialized to ensure that if it were to exceed the magnitude threshold, it is ready to receive data from its adjacent nodes. Upon receiving the information sent from its adjacent nodes, the validation process is as follow:

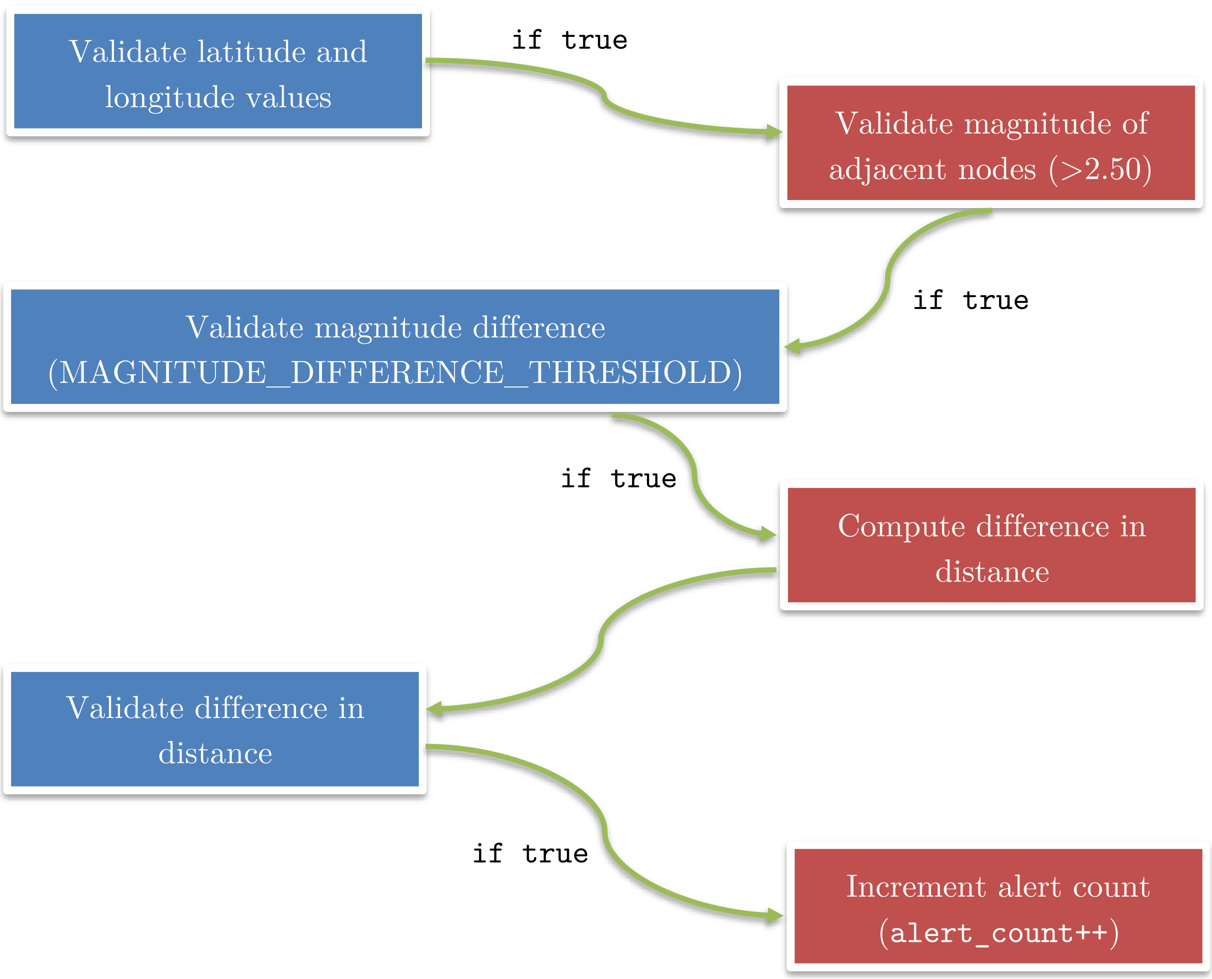

Figure 1.5: Flowchart that simulates the process of validations that were performed when receiving information from adjacent nodes, prior to making an alert.

Reporting of alerts to the base station

As required by assignment specifications, if there's a minimum of 2 alerts, a report which includes information of all adjacent nodes of the reporting node is logged back onto the base station. This includes current date and time, communication time, the latitude, longitude, coordinates, magnitudes and depth values of all the nodes. Prior to sending this information, the reporting node will first send a signal (true value) back to the base station to notify that a report is triggered to facilitate the blocking operation of send and receive through `MPI_Send` and `MPI_Recv`.

The sensor nodes will then sleep for the remaining duration of the 1 second after deducting the time taken to execute the said process above and will continue to run (iterate) until they receive a termination signal from the base station. This termination signal is validated on each iteration, by calling `MPI_Irecv` and `MPI_Test` to determine whether a signal is indeed received. Upon termination, `MPI_Comm_free` is called to deallocate the communicator.

b) Balloon Seismic Sensor

The balloon is initiated on a thread, created by the **Base station** and periodically produces seismic readings based on a set interval of **1** second. The generation process of the latitude, longitude, magnitude and depth values are similar to **(a)** with the main difference being that the magnitude is always a value >**2.5**. The information is stored in a shared global array that has a maximum capacity of **10** and operates based on a *first in, first out* approach.

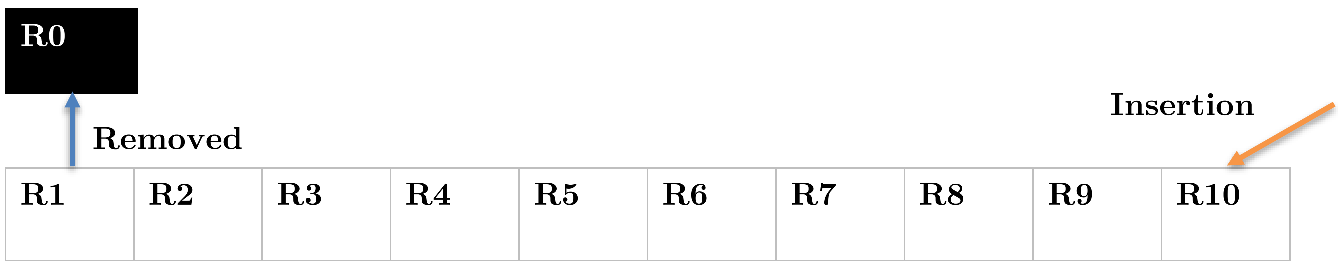

Figure 1.6: First In, First Out Array of Sized 10 (Rx where x denotes each element)

This process is done by shifting the readings to the left of the array when the array is full, and removes the oldest reading, denoted as **R0** to allocate space for **R10**. This array is directly accessible by the base station and the balloon will keep on producing seismic readings on the said interval until it receives a termination signal from the base station and exits.

c) Base Station

Upon initialization, a MPI process simulates the base station and creates a thread to simulate the balloon. The main operation of the base station is to periodically listen for incoming reports and validate whether if there is a match, when comparing with the data produced by the shared global array. This process is shown in the flow chart below:

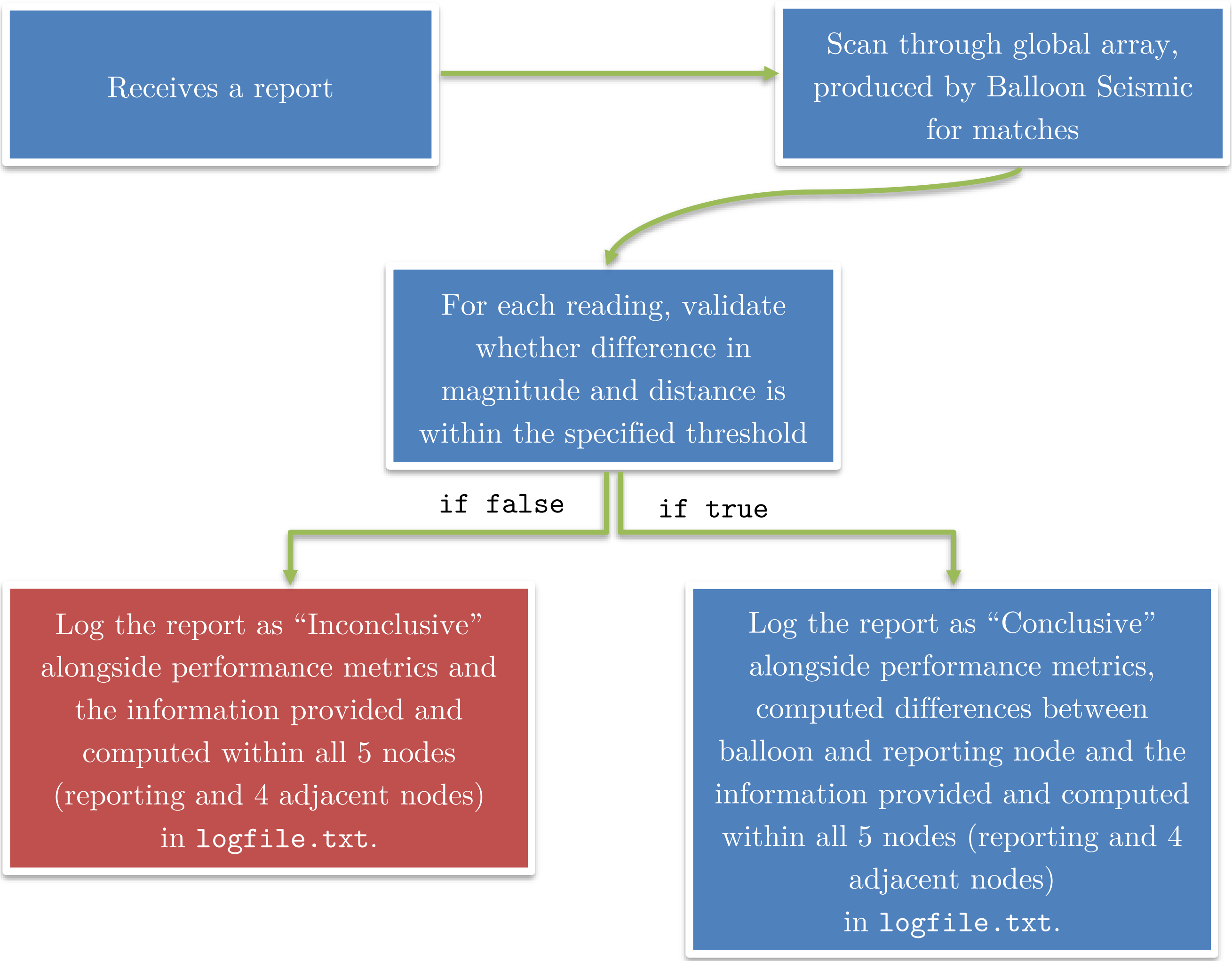

Figure 1.7: Flowchart of how Base Station validates readings from Reporting Node with Balloon Seismic and decides whether an alert is Inconclusive or Conclusive.

Additionally, for both inconclusive and conclusive alerts, they will still be saved in a text file, named `logfile.txt` which will include all important performance metrics, such as information of all **5** nodes (reporting and **4** adjacent nodes), magnitude and distance differences, simulation time, number of alerts detected (matching adjacent nodes) and the number of messages utilized.

This process will continue to iterate until a **sentinel value**, which was specified by the user as the third argument on runtime, is achieved. This sentinel value can be used interchangeably as the iterations or the amount of time to be executed (since iterations are implemented on a time interval basis). Once the sentinel value is met, a proper shutdown is initiated by sending termination message to all of the sensor nodes as well as a termination signal to the balloon to terminate all processes. After that, the base station terminates, and the program exits completely.

B. Results Tabulation

Local Computer Results

To initiate the simulation, simply compile the code through

```
mpicc asgn2.c -o asng2.out -lm
```

To perform execution, simply

```
mpicc -np x+y+1 -oversubscribe asgn2.out x y sentinel
```

where `x` and `y` denote the dimensions, and of course, we have to allocate `x*y+1` number of processes.

```
==================================================================
Number of messages passed throughout network: 56
Number of alerts: 14
Total communication time: 1.214513471
==================================================================
```

Figure 2.1: Summary in logfile.txt

We will be showing some of the reports that were logged in the log file computed as part of the results tabulation. For reference, the following output is based on a 3×4 dimension, executed for 60 seconds and produced a total of 14 reports where 9 are inconclusive, 5 are conclusive alerts with 56 total messages and 1.21s of communication time.

```
==============================================================
Iteration: 3
Logged time: Tue Oct 18 17:14:11 2022
Alert reported time: Tue Oct 18 17:14:11 2022
Alert type: Inconclusive

Reporting Node              Seismic Coord                         Magnitude
2(0, 2)                     (-13.46,160.26)                        2.60

Adjacent Nodes              Seismic Coord       Diff(Coord.km)    Magnitude          Diff(Mag)
1(0, 1)                     (-14.64,160.11)      132.14            2.00               0.60
3(0, 3)                     (-12.28,160.40)      132.09            2.58               0.01
6(1, 2)                     (-13.64,161.84)      172.07            2.91               0.31

This is an inconclusive alert. Thus, no matched entries with balloon seismic.

Communication Time (seconds): 0.087892801
Total Messages send between reporting node and base station: 4
Number of adjacent matches to reporting node: 2
Coordinate difference threshold (km): 180
Magnitude difference threshold: 0.50
Earthquake magnitude threshold: 2.50
==============================================================
==============================================================
```

Figure 2.2: Example log in logfile.txt (1)

ID	Description
1.	In Iteration 3, Node 2 reports an alert to the base station.
2.	The location of seismic readings for nodes 1, 3, 6 are 132.14km, 132.09km and 172.07km away from the seismic reading recorded by Node 2.
3.	The magnitude of seismic readings for nodes 1, 3 and 6 differ from Node 2's reported magnitude by 0.60, 0.01 and 0.31 respectively.
4.	Coordinate difference threshold is 180km (scaled up to improve chances of logging) and magnitude difference threshold is 0.50.
5.	In this context, 2 of the neighbourhood nodes, Node 3 and 6 recorded seismic readings within the specified thresholds across both magnitude and distances, thus, Node 2 reported an alert to the base station.
6.	At that point of time, all of the seismic readings produced by the balloon seismic sensor does not match the reporting Node 2's threshold values. Thus, an inconclusive error was reported.
7.	The communication time utilized was approximately 0.0879 seconds, 4 messages were sent and number of adjacent matches to reporting node is 2.

Table 2.1: Descriptive tabulation explanation of Figure 2.2

```
==================================================================
Iteration: 32
Logged time: Tue Oct 18 17:14:40 2022
Alert reported time: Tue Oct 18 17:14:40 2022
Alert type: Conclusive

Reporting Node              Seismic Coord                         Magnitude
6(1, 2)                     (-13.61,161.74)                        3.07

Adjacent Nodes              Seismic Coord       Diff(Coord.km)    Magnitude           Diff(Mag)
5(1, 1)                     (-14.28,161.74)      74.43             3.05                0.02
7(1, 3)                     (-12.94,161.74)      74.43             2.96                0.11
2(0, 2)                     (-13.19,160.73)      119.05            1.70                1.37
10(2, 2)                     (-13.14,162.75)      121.73            1.87                1.20

Balloon seismic reporting time: 2022-10-18 (H) 17, (M) 14, (S) 39
Balloon seismic reporting Coord: (-14.12,160.71)
Balloon seismic reporting Coord Diff. with Reporting Node (km): 124.99
Balloon seismic reporting Magnitude: 3.18
Balloon seismic reporting Magnitude Diff. with Reporting Node (km): 0.11

Communication Time (seconds): 0.088023942
Total Messages send between reporting node and base station: 4
Number of adjacent matches to reporting node: 2
Coordinate difference threshold (km): 180
Magnitude difference threshold: 0.50
Earthquake magnitude threshold: 2.50
==================================================================
==================================================================
```

Figure 2.3: Example log in logfile.txt (2)

ID	Description
1.	In Iteration 32, Node 6 reports an alert to the base station.
2.	The location of seismic readings for nodes 5, 7, 2 and 10 are 74.43km, 74.43km, 119.05km and 121.73km away from the seismic reading recorded by Node 6.
3.	The magnitude of seismic readings for nodes 5, 7, 2 and 10 differ from Node 6's reported magnitude by 0.02, 0.11, 1.37 and 1.20 respectively.
4.	Coordinate difference threshold is 180km (scaled up to improve chances of logging) and magnitude difference threshold is 0.50.
5.	In this context, 2 of the neighbourhood nodes, Node 5 and 7 recorded seismic readings within the specified thresholds across both magnitude and distances, thus, Node 6 reported an alert to the base station.
6.	At that point of time, at least one of seismic readings produced by the balloon seismic sensor matches the reporting Node 2's threshold values. Thus, a conclusive error was reported.
7.	The communication time utilized was approximately 0.0880 seconds, 4 messages were sent and number of adjacent matches to reporting node is 2.

Table 2.2: Descriptive tabulation explanation of Figure 2.3

```
==================================================================
Iteration: 38
Logged time: Tue Oct 18 17:14:46 2022
Alert reported time: Tue Oct 18 17:14:46 2022
Alert type: Inconclusive

Reporting Node              Seismic Coord                       Magnitude
11(2, 3)                     (-12.49,162.06)                      5.26

Adjacent Nodes              Seismic Coord       Diff(Coord.km)      Magnitude           Diff(Mag)
10(2, 2)                     (-13.46,162.49)      117.22              5.23                0.03
7(1, 3)                     (-12.36,161.88)      24.40               5.65                0.38

This is an inconclusive alert. Thus, no matched entries with balloon seismic.

Communication Time (seconds): 0.088140981
Total Messages send between reporting node and base station: 4
Number of adjacent matches to reporting node: 2
Coordinate difference threshold (km): 180
Magnitude difference threshold: 0.50
Earthquake magnitude threshold: 2.50
==================================================================
==================================================================
```

Figure 2.4: Example log in logfile.txt (3)

ID	Description
1.	In Iteration 38, Node 11 reports an alert to the base station.
2.	The location of seismic readings for nodes 10 and 7 are 117.22km and 24.20km, away from the seismic reading recorded by Node 11.
3.	The magnitude of seismic readings for nodes 10 and 7 differ from Node 11's reported magnitude by 0.03 and 0.38 respectively.
4.	Coordinate difference threshold is 180km (scaled up to improve chances of logging) and magnitude difference threshold is 0.50.
5.	In this context, both of the neighbourhood nodes, Node 10 and 7 recorded seismic readings within the specified thresholds across both magnitude and distances, thus, Node 11 reported an alert to the base station.
6.	At that point of time, at least one of seismic readings produced by the balloon seismic sensor matches the reporting Node 11's threshold values. Thus, a conclusive error was reported.
7.	The communication time utilized was approximately 0.0881 seconds, 4 messages were sent and number of adjacent matches to reporting node is 2.

Table 2.3: Descriptive tabulation explanation of Figure 2.4

CAAS Execution Results

To run the program on CAAS, ensure that the `asgn2.c` program file, alongside with `asgn2_4x4.job` file is included, and execute `sbatch asgn2_4x4.job` on CAAS terminal. The job file is responsible for executing the simulation with a dimension of 4×4, utilizing 16 MPI processes across 2 nodes with each MPI process capable of utilizing a single thread. For reference, the sentinel value here is specified as 60, which will enable the program to run for 60 iterations (i.e., 60 seconds). The description of each value matched with the results when running on a local computer, as shown above. Additionally, the log files produced will be included, named as `4x4_a2_5719.out.`

```
==================================================================
Iteration: 19
Logged time: Tue Oct 18 17:52:30 2022
Alert reported time: Tue Oct 18 17:52:30 2022
Alert type: Conclusive

Reporting Node              Seismic Coord                         Magnitude
14(3, 2)                     (-13.61,163.44)                        3.96

Adjacent Nodes              Seismic Coord       Diff(Coord.km)      Magnitude           Diff(Mag)
13(3, 1)                     (-14.99,163.04)      160.09              4.14                0.18
15(3, 3)                     (-12.22,163.84)      160.16              3.77                0.19
10(2, 2)                     (-13.35,162.63)      91.55               4.65                0.69

Balloon seismic reporting time: 2022-10-18 (H) 17, (M) 52, (S) 21
Balloon seismic reporting Coord: (-15.05,163.33)
Balloon seismic reporting Coord Diff. with Reporting Node (km): 160.98
Balloon seismic reporting Magnitude: 3.48
Balloon seismic reporting Magnitude Diff. with Reporting Node (km): 0.48

Communication Time (seconds): 0.041229955
Total Messages send between reporting node and base station: 4
Number of adjacent matches to reporting node: 2
Coordinate difference threshold (km): 180
Magnitude difference threshold: 0.50
Earthquake magnitude threshold: 2.50
==================================================================
==================================================================
```

Figure 2.5: Example log in 4x4_a2_5719.out (1)

ID	Description
1.	In Iteration 19, Node 14 reports an alert to the base station.
2.	The location of seismic readings for nodes 13, 15 and 10 are 160.09km, 160.16km, and 91.55km, away from the seismic reading recorded by Node 19.
3.	The magnitude of seismic readings for nodes 13, 15 and 10 differ from Node 19's reported magnitude by 0.18, 0.19 and 0.69 respectively.
4.	Coordinate difference threshold is 180km (scaled up to improve chances of logging) and magnitude difference threshold is 0.50.
5.	In this context, both of the neighbourhood nodes, Node 13 and 15 recorded seismic readings within the specified thresholds across both magnitude and distances, thus, Node 19 reported an alert to the base station.

6.	At that point of time, at least one of seismic readings produced by the balloon seismic sensor matches the reporting Node 19's threshold values. Thus, a conclusive error was reported.
7.	The communication time utilized was approximately 0.0412 seconds, 4 messages were sent and number of adjacent matches to reporting node is 2.

Table 2.4: Descriptive tabulation explanation of Figure 2.5

```
================================================================
Iteration: 7
Logged time: Tue Oct 18 17:52:18 2022
Alert reported time: Tue Oct 18 17:52:18 2022
Alert type: Inconclusive

Reporting Node              Seismic Coord                         Magnitude
3(0, 3)                     (-12.94,160.39)                        3.03

Adjacent Nodes              Seismic Coord      Diff(Coord.km)     Magnitude          Diff(Mag)
2(0, 2)                     (-13.73,160.02)     96.44              3.02               0.00
7(1, 3)                     (-12.88,161.06)     72.73              3.20               0.18

This is an inconclusive alert. Thus, no matched entries with balloon seismic.

Communication Time (seconds): 0.048585419
Total Messages send between reporting node and base station: 4
Number of adjacent matches to reporting node: 2
Coordinate difference threshold (km): 180
Magnitude difference threshold: 0.50
Earthquake magnitude threshold: 2.50
================================================================
================================================================
```

Figure 2.6: Example log in 4x4_a2_5719.out (2)

ID	Description
1.	In Iteration 7, Node 3 reports an alert to the base station.
2.	The location of seismic readings for nodes 2 and 7 are 96.44km and 72.73km, away from the seismic reading recorded by Node 3.
3.	The magnitude of seismic readings for nodes 2 and 7 differ from Node 3's reported magnitude by 0.00 and 0.18 respectively.
4.	Coordinate difference threshold is 180km (scaled up to improve chances of logging) and magnitude difference threshold is 0.50.
5.	In this context, both of the neighbourhood nodes, Node 2 and 7 recorded seismic readings within the specified thresholds across both magnitude and distances, thus, Node 3 reported an alert to the base station.
6.	At that point of time, none of the seismic readings produced by the balloon seismic sensor matches the reporting Node 3's threshold values. Thus, an inconclusive error was reported.
7.	The communication time utilized was approximately 0.0486 seconds, 4 messages were sent and number of adjacent matches to reporting node is 2.

Table 2.5: Descriptive tabulation explanation of Figure 2.6

C. Analysis & Discussion

On Local Computer (3x4 dimension, `sentinel_time` = 60)

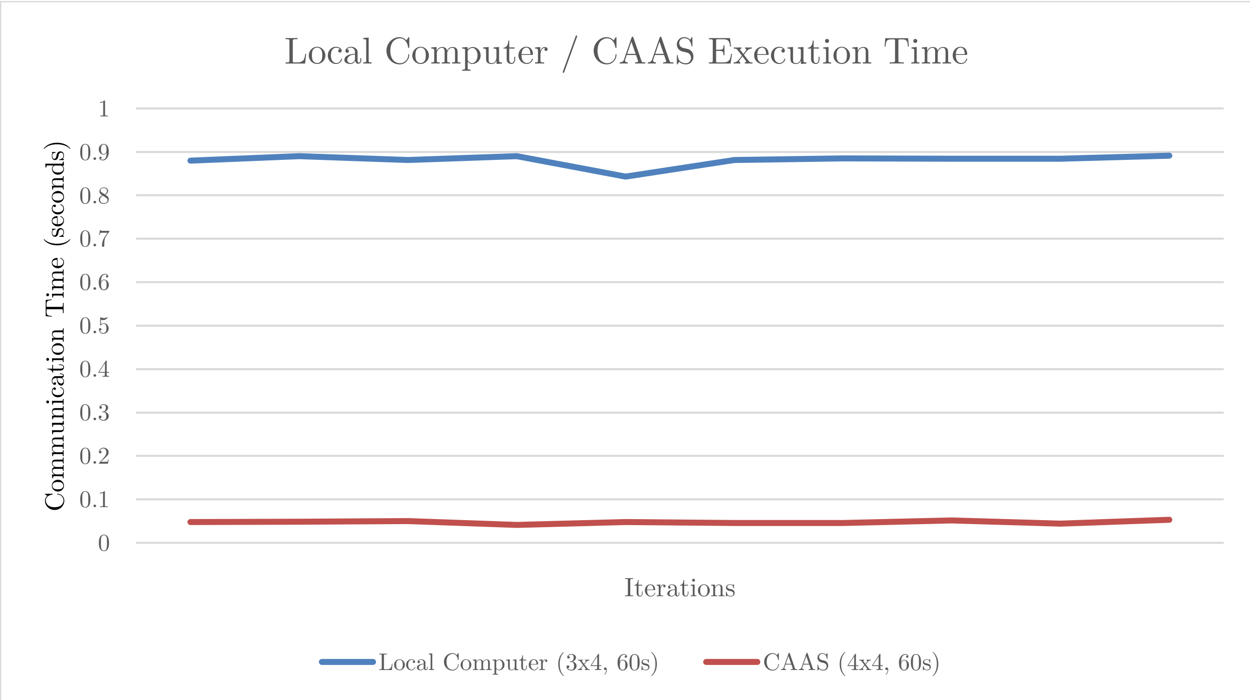

Figure 3.1: Execution time comparison between local computer and CAAS.

The behaviour of the simulator is particularly stable, as the communication time between the seismic sensor nodes and the base station stayed constant at around 0.087 to 0.088 seconds for each iteration with the option `` `--oversubscribe` `` enabled to overcome the lack of hardware threads on the team's local machine.

As for the content of the messages exchanged between the nodes to their adjacent nodes, within the code, we can observe that there is a total of 2 events where `MPI_Isend` is used to communicate between the nodes.

In the first send and receive, the nodes send and receive the trigger Boolean, which activates based on the magnitude values, the second conditional send and receive is based on the adjacent node trigger values and the current node's magnitude values. The sent data consist of a custom datatype which contains the magnitude, longitude and latitude and the received data receives the aforementioned data.

The method of creating a custom datatype to pack the values allows us to only use a single `MPI_Isend` instead of using multiple `MPI_Isend`, and this greatly helps with reducing the communication overhead, and it can help to differentiate values among the sent data.

As for the content of the messages exchanged between the individual nodes and the base station, a minimum of 1 to a maximum of 4 messages is transmitted here. If alert_count reaches or exceeds the threshold, a Boolean message is sent first to notify the base station, then a string message containing the date and time information, then the 5 sensor node information is received, and lastly, the communication time to transmit the message from the sensor node to the base station.

To reiterate from above, the custom datatype is used here to greatly minimize the amount of `MPI_Send` calls to minimize the communication overhead.

On CAAS (4x4 dimension, `sentinel_time` = 60)

In terms of comparing the execution on CAAS and on a local computer, it can be seen that even though the dimension size increased, the communication time between nodes reduced to approximately 0.04 ~ 0.05. The communication time between the sending and receiving reports were quite minimal, even when the program is executed on a local computer. The number of reports triggered depends on the randomness of the generated values as well, which does not serve as a stable comparison metric.

In general, CAAS provides high-performance computing through full utilization of processes as well, instead of having to utilize over-subscribe on local computers, which ensures that we are able to utilize the computing power to full potential, which ultimately grants the small reduction in overall communication time as mentioned.

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D. References

GeoDataSource. (n.d.). *Calculate distance by latitude and longitude using C.* GeoDataSource. Retrieved October 10, 2022, from https://www.geodatasource.com/developers/c

Weighted random float number with single target and chance of hitting target. Stack Overflow. (n.d.). Retrieved October 10, 2022, from https://stackoverflow.com/questions/70341989/weighted-random-float-number-with-single-target-and-chance-of-hitting-target

Declaration:

I declare that this assignment report and the submitted code represent work within my team. I have not copied from any other teams' work or from any other source except where due acknowledgment is made explicitly in the report and code, nor has any part of this submission been written for me by another person outside of my team.

Signature of student 1: Charles Tan Wei Wen

Signature of student 2: Tan June Weng