A Wireless Sensor Network Model of an EV Charging Network

Jiangye Song

Contents

Architecture

Wireless sensor network (WSN) is efficient and flexible due to its traits including fast processing speed, low electric consumption & cost (Z. Hao et al., 2020). The WSN model in this report is an EV charging nodes network, contains a grid of EV charging nodes that can communicate with each other, and a base station. Each EV node has a fixed number of charging ports, which can be occupied (use) by the user. The base node can communicate with all the nodes in the network.

Figures below show two examples of such a network. The blue/orange circles represent the EV nodes/base node, arrows between the nodes means they can communicate with each other. Both examples have 3 charging port per EV node.

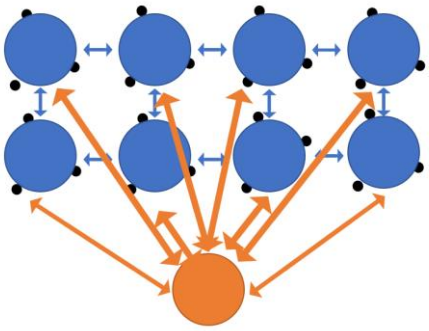


Fig.1: A 2×4 network

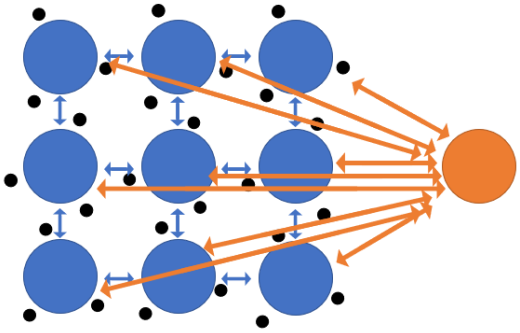


Fig.2: A 3×3 network

Methodology

This section describes the structure of the algorithm, including the main function, charging stations (EV node), and the base station.

Main

The main function is where the program starts. It initializes the MPI environment, processes the command-line arguments, splits the processes into base node process and EV node processes. Then the process will call their corresponding function.

Parameter of the program

The program requires a parameter of size (nodes count).

The user can also specify the column number and row number. If user specify them, it must meet this requirement:

$$ncol \times nrow + 1 = size$$

As we need column × row number of EV nodes, and 1 base node.

If the user does not specify them, the program will use the square root of the size as number of columns & rows.

Selection of the Base Node

Currently, the last process of the program is made as the base node. This will keep the simplicity of the code as (size - 1) will always give the root node; also, for all 'for loops in the code, we can start from 0 which will make the code less confusing.

Flowchart

The overall process is illustrated in the flowchart.

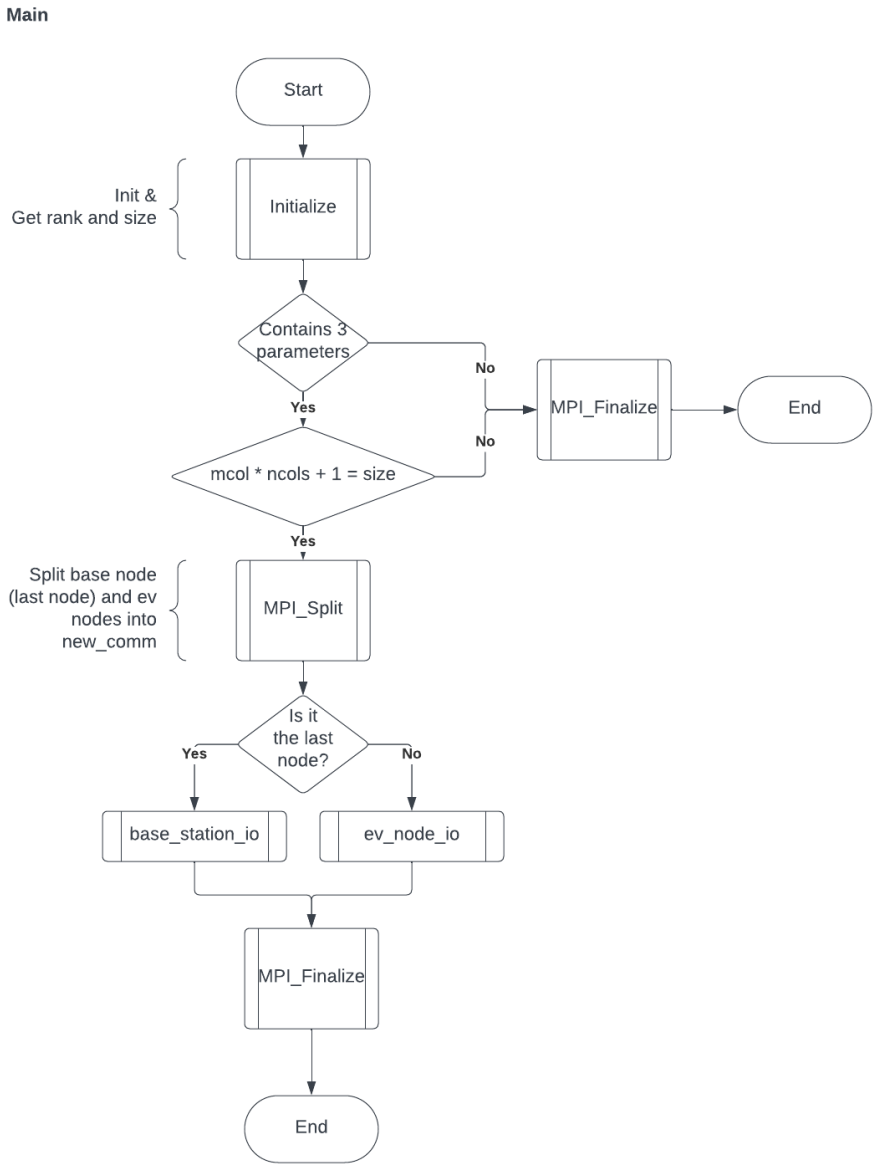


Fig.3: The flowchart of the main function

EV Node

This function represents the logic for each EV charging station node. The processes here will form a cartesian topology. Each node will get their neighbors, then do their tasks iteratively until the base node broadcasts the terminate message.

Initialize

This part of code uses Week 9 Lab as a starting point. Each process will firstly get the world size & rank. MPI_Dims_create will create a division of processors and MPI_Cart_create will create a topology and attach to the comm2d. By doing MPI_Cart_shift on both columns & rows, each process can find their neighbors.

Ports

Ports are simulated by an array of int. They ports are initialize as 0 (FALSE) and will be considered as occupied when they are 1 (TRUE). I have arbitrarily made all ports have a 50/50 chance occupied each iteration, and the ports will not be free again once it occupied.

To make the rand() gives random value different from other processes, a seed of rank plus time is used for srand().

Iteration start

The EV nodes do not know when the program will terminate (so the while loop condition is TRUE). They will listen to the Broadcast from the base node. If the base node sent them a terminal message, they would break the loop; if they received any other message, they would continue to the rest of their code.

Update node status

The algorithm uses an Open MP (OMP) parallel for loop to check & update (one OMP process per port) all the ports as the rule mentioned in Ports. Once a node has been confirmed to remain free, the all_occupied variable (initialized as TRUE) will turn to FALSE.

EV nodes will then MPI send their status to neighbors if and only if they have no port free. All EV nodes will then do MPI irecv to check whether their neighbors sent them a message, if there is no message, the irecv request will then be cancelled. The above processes are implemented in 2 OMP for loops (one OMP process per neighbor). If there is at least one neighbor did not send a message, that means the node has neighbor available (change all_neighbors_full to FALSE, initially TRUE).

Check node status

If the node is not all_occupied, then no action is needed. If the neighbor is all_occupied and all neighbors are also full (denotes as AREA_FULL), it needs to send the alert information to the base node and receive the nearest available node. An additional while loop is used. When the node is all_occupied but not all_neighbors_full, it also needs to report to base node.

After the period report has been printed to the console, the node can go to a new iteration.

Flowchart

The overall process discussed above can be drawn into a flowchart.

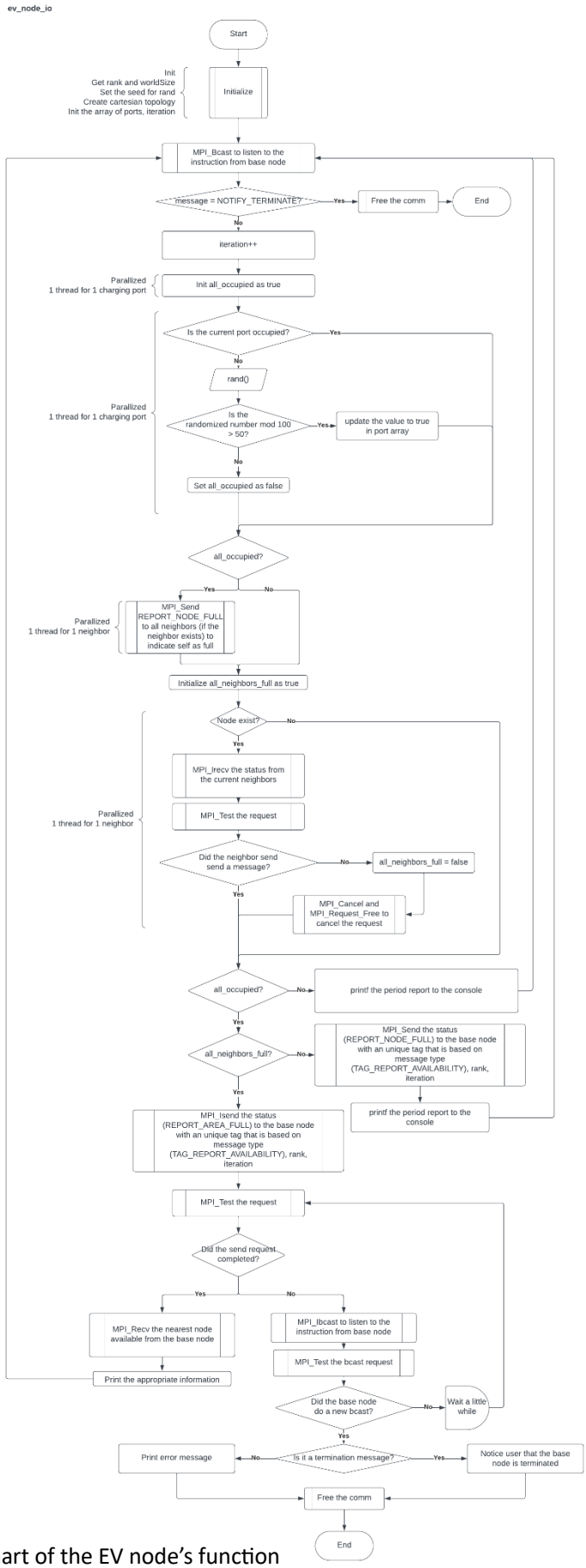


Fig.4: The flowchart of the EV node's function

Base Station

This function is for the station node used to handle termination and nearest node available.

Initialize

It will initialize the world size (number of processes of program), iteration (increase every iteration) and iteration_remain (decrease every iteration).

Iteration start

It uses bcast NONE to notify EV nodes to continue to their iteration, It creates & initialize a nodes_isfull array every iteration.

It then performs sleep for a constant time, sleep is performed here to allow EV nodes have time to process their status and send request (if any).

Update node is full array

The base node uses an OMP for loop (one OMP process for each EV node) to Irecv the send requests and update the array for their status (NODE_FULL/AREA_FULL). If an OMP process did not receives the send request from its node, it cancel the irecv request and take it as available node.

Reply the area full nodes

This happens after the previous step has completed. It will then use another OMP for loop to scan through the array. If and only if the OMP process found its node is AREA_FULL, it will calculate and get the nearest node available.

Nearest node available

Since we have the ncols variable, base node can directly calculate the x and y coordinate (Figure 5). EV node will not send their coordinate to save cost.

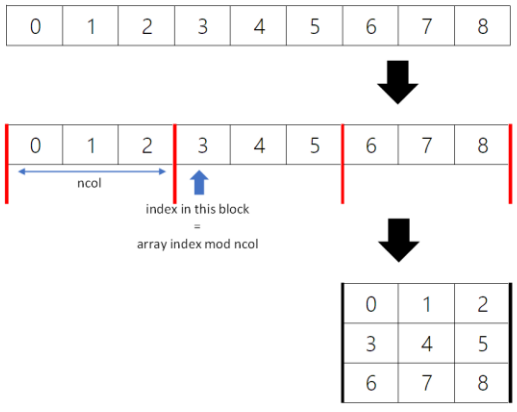


Fig.5: Converting the 1d array back to 2d grid

The algorithm uses a similar way to the “minimum item in array” to find the nearest available. The pseudocode for this part is provided below.

```
// Get the coordinates of the reporting node (i)
i_x = i / ncols
i_y = i MOD ncols
node = NODE_NOT_EXIST
min_distance = INFINITY
FOR j IN [0…EV_NODE_AMOUNT]
    // Check if the node j is free
    IF nodes_isfull[j] IS FREE:
        // Get the coordinates of this free node (j)
        j_x = j / ncols
        j_y = j MOD ncols

        // Calculate Euclidean distance
        dist = SQUARE_ROOT((i_x - j_x)^2 + (i_y - j_y)^2)

        // Update the nearest node if the current distance is smaller
        IF dist < min_distance:
            min_distance = dist
            response = j
```

It sends back the response to the node requested. If no free node found in previous step, it will return the default response value (NODE_NOT_EXIST).

End of loop

The base node reaches the end of the iteration, if the iteration_remain is greater than 0, then it will begin the new iteration.

Termination

If the iteration_remain reaches 0, the loop ends. Base node will bcast the terminate message (NOTIFY_TERMINATE) and return.

Flowchart

The overall process is drawn into flowchart below.

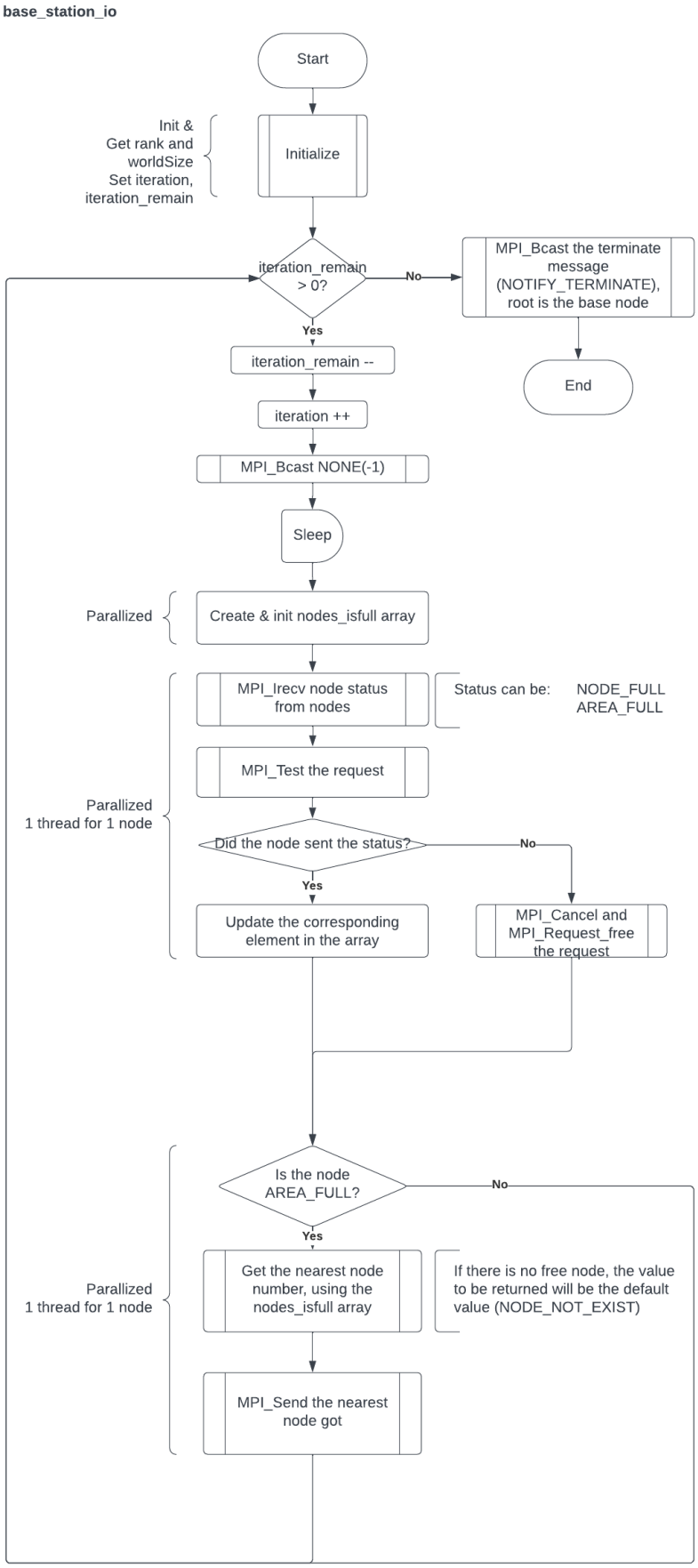


Fig.6: The flowchart of the Base node's function

Results Tabulation

Results

The program was tested on both local machine and CAAS.

To able to test a model with nodes that more than the core numbers, the "--oversubscribe" option is used (Mpirun Command Options, 2021).

Local Machine: 32G memory, CPU core number is 8.
CAAS: the memory is set to 16G, and CPU-per-task is set to 8.

Refresh interval of the program is coded as 2, the maximum iteration in base node is 7, and each node have 5 ports. Notice that the ports are being occupied randomly, so it is normal that reported count aren't the same.

Attempt Runs	Environment	Size	Columns	Rows	Reported count	Period report generated	The worst time taken in base node iteration	The worst worst-time-taken in EV node iteration across all EV nodes	Worst overall time taken across all the nodes
1	Local	9	4	2	36	63	6.250270	10.541274	58.769891
	CAAS	9	4	2	39	63	2.000315	4.000392	16.127866
2	Local	10	3	3	45	70	4.870168	6.953666	49.040056
	CAAS	10	3	3	34	70	2.000507	4.000216	16.139467
3	Local	26	5	5	99	182	6.844990	11.273404	63.251367
	CAAS	26	5	5	114	182	2.001437	4.000607	16.366927

Discussion

By checking the report, it's evident that the program consistently achieved 100% correctness across all test cases.

From the results of the test, all nodes always give the correct period report. Furthermore, the CAAS environment demonstrated a significant performance advantage with an always close to theoretical time. This is might because the local machine limited by the Linux subsystem and need to handle other applications in parallel.

By compare the local machine record #1 and #3, the overall time grows significantly as well when the size grows significantly. This is because the communication time is influence by the number of nodes, which will delay the overall time.

Logs

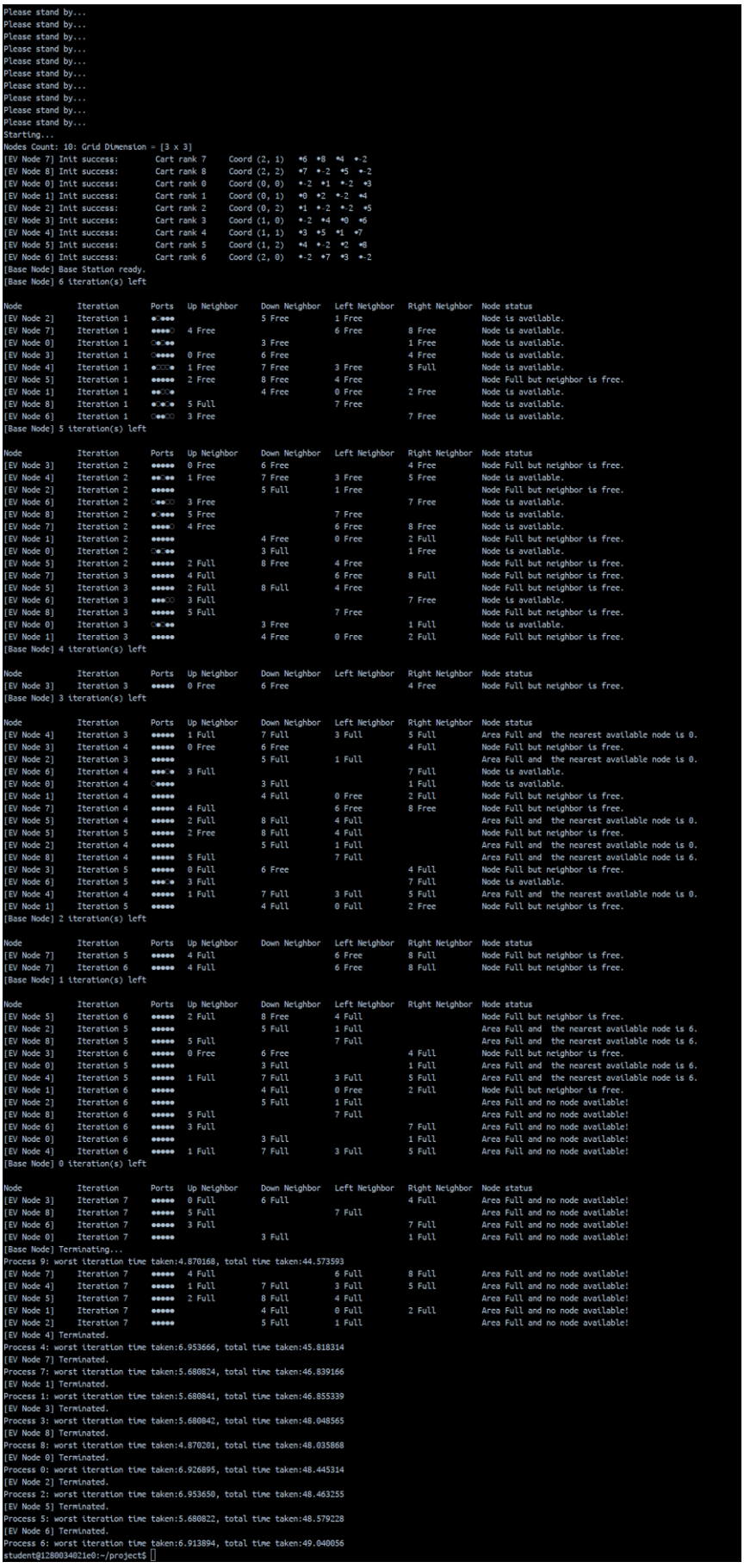
2x4 Local

```
student@1280034021e0:~/project/AS2$ mpirun --oversubscribe -np 9 a.out 2 4
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Starting...
Nodes Count: 9: Grid Dimension = [2 x 4]
[EV Node 0] Init success:  Cart rank 0  Coord (0, 0)□-2  □1  □-2  □2
[EV Node 7] Init success:  Cart rank 7  Coord (3, 1)□6  □-2  □5  □-2
[EV Node 1] Init success:  Cart rank 1  Coord (0, 1)□0  □-2  □-2  □3
[EV Node 2] Init success:  Cart rank 2  Coord (1, 0)□-2  □3  □0  □4
[EV Node 3] Init success:  Cart rank 3  Coord (1, 1)□2  □-2  □1  □5
[EV Node 4] Init success:  Cart rank 4  Coord (2, 0)□-2  □5  □2  □6
[EV Node 6] Init success:  Cart rank 6  Coord (3, 0)□-2  □7  □4  □-2
[EV Node 5] Init success:  Cart rank 5  Coord (2, 1)□4  □-2  □3  □7
[EV Node 3]Iteration 1●○○○1 Free  5 Free  2 Free          Node is available.
[EV Node 4]Iteration 1○○○○2 Free  6 Free          5 Free  Node is available.
[Base Node] Base Station ready.
[Base Node] 6 iteration(s) left

Node      Iteration  Ports  Up Neighbor     Down Neighbor    Left Neighbor   Right NeighborNode status
[EV Node 1]Iteration 1●○○●        3 Free  0 Free           Node is available.
[EV Node 7]Iteration 1○●○○5 Free          6 Free           Node is available.
[EV Node 0]Iteration 1●○●○○        2 Free          1 Free  Node is available.
[EV Node 5]Iteration 1○○○○3 Free  7 Free  4 Free           Node is available.
[EV Node 6]Iteration 1○○○●4 Free                  7 Free  Node is available.
[EV Node 2]Iteration 1○●○○○0 Free  4 Free          3 Free  Node is available.
[EV Node 2]Iteration 2○●○●○0 Free  4 Free          3 Free  Node is available.
[EV Node 4]Iteration 2○●●○2 Free  6 Free          5 Free  Node is available.
[EV Node 1]Iteration 2●●●●●        3 Full  0 Free           Node Full but neighbor is free.
[Base Node] 5 iteration(s) left

Node      Iteration  Ports  Up Neighbor     Down Neighbor    Left Neighbor   Right NeighborNode status
[EV Node 6]Iteration 2○●●●4 Free                  7 Full  Node is available.
[EV Node 0]Iteration 2●○●●○        2 Free          1 Free  Node is available.
[EV Node 3]Iteration 2●●●●1 Full  5 Free  2 Free           Node Full but neighbor is free.
[EV Node 5]Iteration 2●●●●3 Full  7 Full  4 Free           Node Full but neighbor is free.
[EV Node 7]Iteration 2●●●●5 Free          6 Free           Node Full but neighbor is free.
[EV Node 2]Iteration 3○●●●0 Free  4 Free          3 Full  Node is available.
[EV Node 4]Iteration 3○●●●2 Free  6 Free          5 Full  Node is available.
[EV Node 1]Iteration 3●●●●●        3 Full  0 Free           Node Full but neighbor is free.
[Base Node] 4 iteration(s) left

Node      Iteration  Ports  Up Neighbor     Down Neighbor    Left Neighbor   Right NeighborNode status
[EV Node 6]Iteration 3●●●●4 Free                  7 Full  Node Full but neighbor is free.
[EV Node 0]Iteration 3●●●●●        2 Free          1 Full  Node Full but neighbor is free.
[EV Node 3]Iteration 3●●●●1 Full  5 Full  2 Free           Node Full but neighbor is free.
[EV Node 7]Iteration 3●●●●5 Full          6 Free           Node Full but neighbor is free.
[EV Node 5]Iteration 3●●●●3 Full  7 Full  4 Free           Node Full but neighbor is free.
[EV Node 4]Iteration 4○●●●2 Free  6 Full          5 Full  Node is available.
[Base Node] 3 iteration(s) left

Node      Iteration  Ports  Up Neighbor     Down Neighbor    Left Neighbor   Right NeighborNode status
[EV Node 6]Iteration 4●●●●4 Free                  7 Full  Node Full but neighbor is free.
[EV Node 0]Iteration 4●●●●●        2 Free          1 Full  Node Full but neighbor is free.
[EV Node 5]Iteration 4●●●●3 Free  7 Full  4 Free           Node Full but neighbor is free.
[EV Node 3]Iteration 4●●●●1 Full  5 Full  2 Free           Node Full but neighbor is free.
[EV Node 2]Iteration 4○●●●0 Full  4 Free          3 Full  Node is available.
[EV Node 0]Iteration 5●●●●●        2 Free          1 Full  Node Full but neighbor is free.
[EV Node 1]Iteration 4●●●●●        3 Full  0 Full           Area Full and  the nearest available node is 2.
[EV Node 1]Iteration 5●●●●●        3 Free  0 Full           Node Full but neighbor is free.
[EV Node 4]Iteration 5○●●●2 Free  6 Full          5 Full  Node is available.
[Base Node] 2 iteration(s) left

Node      Iteration  Ports  Up Neighbor     Down Neighbor    Left Neighbor   Right NeighborNode status
[EV Node 6]Iteration 5●●●●4 Free                  7 Full  Node Full but neighbor is free.
[EV Node 2]Iteration 5○●●●0 Full  4 Free          3 Full  Node is available.
[EV Node 7]Iteration 4●●●●5 Full          6 Full           Area Full and  the nearest available node is 2.
[EV Node 5]Iteration 5●●●●3 Full  7 Full  4 Free           Node Full but neighbor is free.
[EV Node 3]Iteration 5●●●●1 Full  5 Full  2 Free           Node Full but neighbor is free.
[EV Node 7]Iteration 5●●●●5 Full          6 Full           Area Full and  the nearest available node is 2.
[EV Node 6]Iteration 6●●●●4 Free                  7 Full  Node Full but neighbor is free.
[EV Node 4]Iteration 6○●●●2 Full  6 Full          5 Full  Node is available.
[Base Node] 1 iteration(s) left

Node      Iteration  Ports  Up Neighbor     Down Neighbor    Left Neighbor   Right NeighborNode status
[EV Node 3]Iteration 6●●●●1 Free  5 Full  2 Full           Node Full but neighbor is free.
[EV Node 2]Iteration 6●●●●0 Full  4 Free          3 Full  Node Full but neighbor is free.
[EV Node 5]Iteration 6●●●●3 Full  7 Full  4 Free           Node Full but neighbor is free.
[Base Node] 0 iteration(s) left

Node      Iteration  Ports  Up Neighbor     Down Neighbor    Left Neighbor   Right NeighborNode status
[EV Node 2]Iteration 7●●●●0 Full  4 Free          3 Full  Node Full but neighbor is free.
[EV Node 7]Iteration 6●●●●5 Full          6 Full           Area Full and  the nearest available node is 4.
[EV Node 0]Iteration 6●●●●●        2 Full          1 Full  Area Full and  the nearest available node is 4.
[EV Node 1]Iteration 6●●●●●        3 Full  0 Full           Area Full and  the nearest available node is 4.
[EV Node 6]Iteration 7●●●●4 Free                  7 Full  Node Full but neighbor is free.
[EV Node 4]Iteration 7○●●●2 Full  6 Full          5 Full  Node is available.
[EV Node 5]Iteration 7●●●●3 Full  7 Full  4 Free           Node Full but neighbor is free.
[EV Node 1]Iteration 7●●●●●        3 Full  0 Full           Area Full and  the nearest available node is 4.
[EV Node 3]Iteration 7●●●●1 Full  5 Full  2 Full           Area Full and  the nearest available node is 4.
[Base Node] Terminating...
Process 8: worst iteration time taken:6.250270, total time taken:54.265990
[EV Node 7]Iteration 7●●●●5 Full          6 Full           Area Full and  the nearest available node is 4.
[EV Node 0]Iteration 7●●●●●        2 Full          1 Full  Area Full and  the nearest available node is 4.
[EV Node 4] Terminated.
Process 4: worst iteration time taken:6.250209, total time taken:55.587105
[EV Node 6] Terminated.
Process 6: worst iteration time taken:6.250249, total time taken:57.320986
[EV Node 2] Terminated.
Process 2: worst iteration time taken:6.250255, total time taken:57.342642
[EV Node 5] Terminated.
Process 5: worst iteration time taken:6.250216, total time taken:57.424590
[EV Node 1] Terminated.
Process 1: worst iteration time taken:10.541274, total time taken:58.594938
[EV Node 0] Terminated.
Process 0: worst iteration time taken:10.541246, total time taken:58.647053
[EV Node 7] Terminated.
Process 7: worst iteration time taken:8.839592, total time taken:58.679124
[EV Node 3] Terminated.
Process 3: worst iteration time taken:9.050251, total time taken:58.769891
```

2x4 CAAS

```
[json0041@student-caas-headnode AS2]$ cat MPI_cg.11088.out
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Starting...
Nodes Count: 9: Grid Dimension = [2 x 4]
[EV Node 1] Init success:       Cart rank 1     Coord (0, 1)   •0  •-2  •-2  •3
[EV Node 2] Init success:       Cart rank 2     Coord (1, 0)   •-2  •3  •0  •4
[EV Node 3] Init success:       Cart rank 3     Coord (1, 1)   •2  •-2  •1  •5
[EV Node 4] Init success:       Cart rank 4     Coord (2, 0)   •-2  •5  •2  •6
[EV Node 5] Init success:       Cart rank 5     Coord (2, 1)   •4  •-2  •3  •7
[EV Node 6] Init success:       Cart rank 6     Coord (3, 0)   •-2  •7  •4  •-2
[EV Node 7] Init success:       Cart rank 7     Coord (3, 1)   •6  •-2  •5  •-2
[EV Node 0] Init success:       Cart rank 0     Coord (0, 0)   •-2  •1  •-2  •2
[Base Node] Base Station ready.
[Base Node] 6 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 7]     Iteration 1     ●●●○●   5 Free                          6 Free                          Node is available.
[EV Node 1]     Iteration 1     ●●●●○                   3 Free          0 Free                          Node is available.
[EV Node 2]     Iteration 1     ●○○●○   0 Free          4 Free                          3 Free          Node is available.
[EV Node 4]     Iteration 1     ●●○○○   2 Free          6 Free                          5 Free          Node is available.
[EV Node 5]     Iteration 1     ●●●●○   3 Free          7 Free          4 Free                          Node is available.
[EV Node 3]     Iteration 1     ○●●●○   1 Free          5 Free          2 Free                          Node is available.
[EV Node 6]     Iteration 1     ●○○●●   4 Free                                          7 Free          Node is available.
[EV Node 0]     Iteration 1     ○●○○●                   2 Free                          1 Free          Node is available.
[Base Node] 5 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 2]     Iteration 2     ●●○●○   0 Free          4 Free                          3 Free          Node is available.
[EV Node 4]     Iteration 2     ●●○●○   2 Free          6 Free                          5 Free          Node is available.
[EV Node 7]     Iteration 2     ●●●○●   5 Free                          6 Free                          Node is available.
[EV Node 6]     Iteration 2     ●●●●●   4 Free                                          7 Free          Node Full but neighbor is free.
[EV Node 0]     Iteration 2     ○●●●●                   2 Free                          1 Full          Node is available.
[EV Node 1]     Iteration 2     ●●●●●                   3 Full          0 Free                          Node Full but neighbor is free.
[EV Node 3]     Iteration 2     ●●●●●   1 Full          5 Free          2 Free                          Node Full but neighbor is free.
[EV Node 4]     Iteration 3     ●●●●○   2 Free          6 Full                          5 Full          Node is available.
[EV Node 5]     Iteration 2     ●●●●●   3 Full          7 Free          4 Free                          Node Full but neighbor is free.
[Base Node] 4 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 5]     Iteration 3     ●●●●●   3 Full          7 Free          4 Free                          Node Full but neighbor is free.
[EV Node 2]     Iteration 3     ●●●●●   0 Free          4 Free                          3 Full          Node Full but neighbor is free.
[EV Node 1]     Iteration 3     ●●●●●                   3 Full          0 Free                          Node Full but neighbor is free.
[EV Node 7]     Iteration 3     ●●●○●   5 Full                          6 Full                          Node is available.
[EV Node 3]     Iteration 3     ●●●●●   1 Full          5 Full          2 Free                          Node Full but neighbor is free.
[EV Node 0]     Iteration 3     ○●●●●                   2 Free                          1 Full          Node is available.
[EV Node 6]     Iteration 3     ●●●●●   4 Free                                          7 Free          Node Full but neighbor is free.
[EV Node 7]     Iteration 4     ●●●○●   5 Full                          6 Full                          Node is available.
[Base Node] 3 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 5]     Iteration 4     ●●●●●   3 Full          7 Free          4 Full                          Node Full but neighbor is free.
[EV Node 2]     Iteration 4     ●●●●●   0 Free          4 Full                          3 Full          Node Full but neighbor is free.
[EV Node 1]     Iteration 4     ●●●●●                   3 Full          0 Free                          Node Full but neighbor is free.
[EV Node 6]     Iteration 4     ●●●●●   4 Full                                          7 Free          Node Full but neighbor is free.
[EV Node 4]     Iteration 4     ●●●●●   2 Full          6 Full                          5 Full          Area Full and  the nearest available node is 7.
[Base Node] 2 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 3]     Iteration 4     ●●●●●   1 Full          5 Full          2 Full                          Area Full and  the nearest available node is 7.
[EV Node 7]     Iteration 5     ●●●○●   5 Full                          6 Full                          Node is available.
[EV Node 5]     Iteration 5     ●●●●●   3 Full          7 Free          4 Full                          Node Full but neighbor is free.
[EV Node 6]     Iteration 5     ●●●●●   4 Full                                          7 Free          Node Full but neighbor is free.
[EV Node 0]     Iteration 4     ●●●●●                   2 Full                          1 Full          Area Full and  the nearest available node is 7.
[EV Node 2]     Iteration 5     ●●●●●   0 Full          4 Full                          3 Full          Area Full and  the nearest available node is 7.
[EV Node 1]     Iteration 5     ●●●●●                   3 Full          0 Full                          Area Full and  the nearest available node is 7.
[Base Node] 1 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 3]     Iteration 5     ●●●●●   1 Full          5 Full          2 Full                          Area Full and  the nearest available node is 7.
[EV Node 4]     Iteration 5     ●●●●●   2 Full          6 Full                          5 Full          Area Full and  the nearest available node is 7.
[EV Node 0]     Iteration 5     ●●●●●                   2 Full                          1 Full          Area Full and  the nearest available node is 7.
[EV Node 4]     Iteration 6     ●●●●●   2 Full          6 Full                          5 Full          Area Full and no node available!
[EV Node 6]     Iteration 6     ●●●●●   4 Full                                          7 Full          Area Full and no node available!
[EV Node 2]     Iteration 6     ●●●●●   0 Full          4 Full                          3 Full          Area Full and no node available!
[EV Node 1]     Iteration 6     ●●●●●                   3 Full          0 Full                          Area Full and no node available!
[EV Node 5]     Iteration 6     ●●●●●   3 Full          7 Full          4 Full                          Area Full and no node available!
[Base Node] 0 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 3]     Iteration 6     ●●●●●   1 Full          5 Full          2 Full                          Area Full and no node available!
[EV Node 7]     Iteration 6     ●●●●●   5 Full                          6 Full                          Area Full and no node available!
[EV Node 0]     Iteration 6     ●●●●●                   2 Full                          1 Full          Area Full and no node available!
[EV Node 7]     Iteration 7     ●●●●●   5 Full                          6 Full                          Area Full and no node available!
[EV Node 4]     Iteration 7     ●●●●●   2 Full          6 Full                          5 Full          Area Full and no node available!
[EV Node 6]     Iteration 7     ●●●●●   4 Full                                          7 Full          Area Full and no node available!
[EV Node 2]     Iteration 7     ●●●●●   0 Full          4 Full                          3 Full          Area Full and no node available!
[EV Node 1]     Iteration 7     ●●●●●                   3 Full          0 Full                          Area Full and no node available!
[EV Node 5]     Iteration 7     ●●●●●   3 Full          7 Full          4 Full                          Area Full and no node available!
[Base Node] Terminating...
Process 8: worst iteration time taken:2.000315, total time taken:15.110662
[EV Node 3]     Iteration 7     ●●●●●   1 Full          5 Full          2 Full                          Area Full and no node available!
[EV Node 0]     Iteration 7     ●●●●●                   2 Full                          1 Full          Area Full and no node available!
[EV Node 1] Terminated.
Process 1: worst iteration time taken:4.000223, total time taken:16.126452
[EV Node 5] Terminated.
Process 5: worst iteration time taken:4.000392, total time taken:16.118634
[EV Node 0] Terminated.
[EV Node 3] Terminated.
Process 3: worst iteration time taken:4.000237, total time taken:16.122776
[EV Node 7] Terminated.
Process 7: worst iteration time taken:4.000212, total time taken:16.113264
[EV Node 4] Terminated.
Process 4: worst iteration time taken:4.000274, total time taken:16.120233
          orst iteration time taken:4.000212, total time taken:16.113264
[EV Node 4] Terminated.
Process 4: worst iteration time taken:4.000274, total time taken:16.120233
[EV Node 6] Terminated.
Process 6: worst iteration time taken:4.000175, total time taken:16.117569
[EV Node 2] Terminated.
```

3x3 Local



```
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Starting...
Nodes Count: 10: Grid Dimension = [3 x 3]
[EV Node 7] Init success:       Cart rank 7     Coord (2, 1)   *6  *8  *4  *-2
[EV Node 8] Init success:       Cart rank 8     Coord (2, 2)   *7  *-2  *5  *-2
[EV Node 0] Init success:       Cart rank 0     Coord (0, 0)   *-2  *1  *-2  *3
[EV Node 1] Init success:       Cart rank 1     Coord (0, 1)   *0  *2  *-2  *4
[EV Node 2] Init success:       Cart rank 2     Coord (0, 2)   *1  *-2  *-2  *5
[EV Node 3] Init success:       Cart rank 3     Coord (1, 0)   *-2  *4  *0  *6
[EV Node 4] Init success:       Cart rank 4     Coord (1, 1)   *3  *5  *1  *7
[EV Node 5] Init success:       Cart rank 5     Coord (1, 2)   *4  *-2  *2  *8
[EV Node 6] Init success:       Cart rank 6     Coord (2, 0)   *-2  *7  *3  *-2
[Base Node] Base Station ready.
[Base Node] 6 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 2]     Iteration 1     ●○●●●                   5 Free                          1 Free                          Node is available.
[EV Node 7]     Iteration 1     ●●●●○   4 Free                                          6 Free          8 Free          Node is available.
[EV Node 0]     Iteration 1     ○●○●●                   3 Free                                          1 Free          Node is available.
[EV Node 3]     Iteration 1     ○●●●●   0 Free          6 Free                                          4 Free          Node is available.
[EV Node 4]     Iteration 1     ●○○○●   1 Free          7 Free          3 Free          5 Full          Node is available.
[EV Node 5]     Iteration 1     ●●●●●   2 Free          8 Free          4 Free                          Node Full but neighbor is free.
[EV Node 1]     Iteration 1     ●●○○●                   4 Free          0 Free          2 Free          Node is available.
[EV Node 8]     Iteration 1     ●○●○●   5 Full                          7 Free                          Node is available.
[EV Node 6]     Iteration 1     ○●●○○   3 Free                                                          7 Free          Node is available.
[Base Node] 5 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 3]     Iteration 2     ●●●●●   0 Free          6 Free                          4 Free          Node Full but neighbor is free.
[EV Node 4]     Iteration 2     ●●○●●   1 Free          7 Free          3 Free          5 Free          Node is available.
[EV Node 2]     Iteration 2     ●●●●●                   5 Full          1 Free                          Node Full but neighbor is free.
[EV Node 6]     Iteration 2     ○●●○○   3 Free                                                          7 Free          Node is available.
[EV Node 8]     Iteration 2     ●○●●●   5 Free                                          7 Free          Node is available.
[EV Node 7]     Iteration 2     ●●●●○   4 Free                                          6 Free          8 Free          Node is available.
[EV Node 1]     Iteration 2     ●●●●●                   4 Free          0 Free          2 Full          Node Full but neighbor is free.
[EV Node 0]     Iteration 2     ○●○●●                   3 Full                                          1 Free          Node is available.
[EV Node 5]     Iteration 2     ●●●●●   2 Full          8 Free          4 Free                          Node Full but neighbor is free.
[EV Node 7]     Iteration 3     ●●●●●   4 Full                                          6 Free          8 Full          Node Full but neighbor is free.
[EV Node 5]     Iteration 3     ●●●●●   2 Full          8 Full          4 Free                          Node Full but neighbor is free.
[EV Node 6]     Iteration 3     ●●●○○   3 Full                                                          7 Free          Node is available.
[EV Node 8]     Iteration 3     ●●●●●   5 Full                                          7 Free                          Node Full but neighbor is free.
[EV Node 0]     Iteration 3     ○●○●●                   3 Free                                          1 Full          Node is available.
[EV Node 1]     Iteration 3     ●●●●●                   4 Free          0 Free          2 Full          Node Full but neighbor is free.
[Base Node] 4 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 3]     Iteration 3     ●●●●●   0 Free          6 Free                          4 Free          Node Full but neighbor is free.
[Base Node] 3 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 4]     Iteration 3     ●●●●●   1 Full          7 Full          3 Full          5 Full          Area Full and  the nearest available node is 0.
[EV Node 3]     Iteration 4     ●●●●●   0 Free          6 Free                          4 Full          Node Full but neighbor is free.
[EV Node 2]     Iteration 3     ●●●●●                   5 Full          1 Full                          Area Full and  the nearest available node is 0.
[EV Node 6]     Iteration 4     ●●●○●   3 Full                                                          7 Full          Node is available.
[EV Node 0]     Iteration 4     ○●●●●                   3 Full                                          1 Full          Node is available.
[EV Node 1]     Iteration 4     ●●●●●                   4 Full          0 Free          2 Full          Node Full but neighbor is free.
[EV Node 7]     Iteration 4     ●●●●●   4 Full                                          6 Free          8 Free          Node Full but neighbor is free.
[EV Node 5]     Iteration 4     ●●●●●   2 Full          8 Full          4 Full                          Area Full and  the nearest available node is 0.
[EV Node 5]     Iteration 5     ●●●●●   2 Free          8 Full          4 Full                          Node Full but neighbor is free.
[EV Node 2]     Iteration 4     ●●●●●                   5 Full          1 Full                          Area Full and  the nearest available node is 0.
[EV Node 8]     Iteration 4     ●●●●●   5 Full                          7 Full                          Area Full and  the nearest available node is 6.
[EV Node 3]     Iteration 5     ●●●●●   0 Full          6 Free                          4 Full          Node Full but neighbor is free.
[EV Node 6]     Iteration 5     ●●●○●   3 Full                                                          7 Full          Node is available.
[EV Node 4]     Iteration 4     ●●●●●   1 Full          7 Full          3 Full          5 Full          Area Full and  the nearest available node is 0.
[EV Node 1]     Iteration 5     ●●●●●                   4 Full          0 Full          2 Free          Node Full but neighbor is free.
[Base Node] 2 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 7]     Iteration 5     ●●●●●   4 Full                                          6 Free          8 Full          Node Full but neighbor is free.
[EV Node 7]     Iteration 6     ●●●●●   4 Full                                          6 Free          8 Full          Node Full but neighbor is free.
[Base Node] 1 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 5]     Iteration 6     ●●●●●   2 Full          8 Free          4 Full                          Node Full but neighbor is free.
[EV Node 2]     Iteration 5     ●●●●●                   5 Full          1 Full                          Area Full and  the nearest available node is 6.
[EV Node 8]     Iteration 5     ●●●●●   5 Full                          7 Full                          Area Full and  the nearest available node is 6.
[EV Node 3]     Iteration 6     ●●●●●   0 Free          6 Free                          4 Full          Node Full but neighbor is free.
[EV Node 0]     Iteration 5     ●●●●●                   3 Full                                          1 Full          Area Full and  the nearest available node is 6.
[EV Node 4]     Iteration 5     ●●●●●   1 Full          7 Full          3 Full          5 Full          Area Full and  the nearest available node is 6.
[EV Node 1]     Iteration 6     ●●●●●                   4 Full          0 Free          2 Full          Node Full but neighbor is free.
[EV Node 2]     Iteration 6     ●●●●●                   5 Full          1 Full                          Area Full and no node available!
[EV Node 8]     Iteration 6     ●●●●●   5 Full                          7 Full                          Area Full and no node available!
[EV Node 6]     Iteration 6     ●●●●●   3 Full                                                          7 Full          Area Full and no node available!
[EV Node 0]     Iteration 6     ●●●●●                   3 Full                                          1 Full          Area Full and no node available!
[EV Node 4]     Iteration 6     ●●●●●   1 Full          7 Full          3 Full          5 Full          Area Full and no node available!
[Base Node] 0 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 3]     Iteration 7     ●●●●●   0 Full          6 Full                          4 Full          Area Full and no node available!
[EV Node 8]     Iteration 7     ●●●●●   5 Full                          7 Full                          Area Full and no node available!
[EV Node 6]     Iteration 7     ●●●●●   3 Full                                                          7 Full          Area Full and no node available!
[EV Node 0]     Iteration 7     ●●●●●                   3 Full                                          1 Full          Area Full and no node available!
[Base Node] Terminating...
Process 9: worst iteration time taken:4.870168, total time taken:44.573593
[EV Node 7]     Iteration 7     ●●●●●   4 Full                                          6 Full          8 Full          Area Full and no node available!
[EV Node 4]     Iteration 7     ●●●●●   1 Full          7 Full          3 Full          5 Full          Area Full and no node available!
[EV Node 5]     Iteration 7     ●●●●●   2 Full          8 Full          4 Full                          Area Full and no node available!
[EV Node 1]     Iteration 7     ●●●●●                   4 Full          0 Full          2 Full          Area Full and no node available!
[EV Node 2]     Iteration 7     ●●●●●                   5 Full          1 Full                          Area Full and no node available!
[EV Node 4] Terminated.
Process 4: worst iteration time taken:6.953666, total time taken:45.818314
[EV Node 7] Terminated.
Process 7: worst iteration time taken:5.680824, total time taken:46.839166
[EV Node 1] Terminated.
Process 1: worst iteration time taken:5.680841, total time taken:46.855339
[EV Node 3] Terminated.
Process 3: worst iteration time taken:5.680842, total time taken:48.048565
[EV Node 8] Terminated.
Process 8: worst iteration time taken:4.870201, total time taken:48.035868
[EV Node 0] Terminated.
Process 0: worst iteration time taken:6.926895, total time taken:48.445314
[EV Node 2] Terminated.
Process 2: worst iteration time taken:6.953650, total time taken:48.463255
[EV Node 5] Terminated.
Process 5: worst iteration time taken:5.680822, total time taken:48.579228
[EV Node 6] Terminated.
Process 6: worst iteration time taken:6.913894, total time taken:49.040056
student@1280034021e0:~/project$
```

3x3 CAAS

```
[json0041@student-caas-headnode AS2]$ cat MPI_cg.11130.out
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Please stand by...
Starting...
Nodes Count: 10: Grid Dimension = [3 x 3]
[EV Node 1] Init success:       Cart rank 1     Coord (0, 1)   •0  •2  •-2  •4
[EV Node 2] Init success:       Cart rank 2     Coord (0, 2)   •1  •-2  •-2  •5
[EV Node 3] Init success:       Cart rank 3     Coord (1, 0)   •-2  •4  •0  •6
[EV Node 5] Init success:       Cart rank 5     Coord (1, 2)   •4  •-2  •2  •8
[EV Node 6] Init success:       Cart rank 6     Coord (2, 0)   •-2  •7  •3  •-2
[EV Node 7] Init success:       Cart rank 7     Coord (2, 1)   •6  •8  •4  •-2
[EV Node 8] Init success:       Cart rank 8     Coord (2, 2)   •7  •-2  •5  •-2
[EV Node 0] Init success:       Cart rank 0     Coord (0, 0)   •-2  •1  •-2  •3
[EV Node 4] Init success:       Cart rank 4     Coord (1, 1)   •3  •5  •1  •7
[Base Node] Base Station ready.
[Base Node] 6 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 1]     Iteration 1     ●●○●○                   4 Free          0 Free          2 Free          Node is available.
[EV Node 7]     Iteration 1     ●●●●○   4 Free                          6 Free          8 Free          Node is available.
[EV Node 8]     Iteration 1     ●○●○○   5 Free                          7 Free                          Node is available.
[EV Node 2][EV Node 0]  Iteration 1     ●●○○○                   3 Free                          1 Free          Node is available.
[EV Node 5]     Iteration 1     ○●●○●   2 Free          8 Free          4 Free                          Node is available.
[EV Node 4]     Iteration 1     ○●●○●   Iteration 1     ○○○○●                   5 Free          1 Free                          Node is available.
[EV Node 3]     Iteration 1     ○○●○●   0 Free          6 Free                                  4 Free          Node is available.
        1 Free          7 Free          3 Free          5 Free          Node is available.
[EV Node 6]     Iteration 1     ○●○○●   3 Free                                                  7 Free          Node is available.
[Base Node] 5 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 7]     Iteration 2     ●●●●●   4 Full                          6 Free          8 Free          Node Full but neighbor is free.
[EV Node 6]     Iteration 2     ○●●●●   3 Free                                                  7 Free          Node is available.
[EV Node 8]     Iteration 2     ●●●●○   5 Free                          7 Free                          Node is available.
[EV Node 3]     Iteration 2     ●○●○●   0 Free          6 Free                                  4 Free          Node is available.
[EV Node 2]     Iteration 2     ○○●●●                   5 Free          1 Free                          Node is available.
[EV Node 0]     Iteration 2     ●●●○●                   3 Free                                  1 Free          Node is available.
[EV Node 1]     Iteration 2     ●●○●●                   4 Free          0 Free          2 Free          Node is available.
[EV Node 5]     Iteration 2     ○●●●●   2 Free          8 Free          4 Free                          Node is available.
[Base Node] 4 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 4]     Iteration 2     ●●●●●   1 Free          7 Full          3 Free          5 Free          Node Full but neighbor is free.
[EV Node 8]     Iteration 3     ●●●●○   5 Free                          7 Full                          Node is available.
[EV Node 2]     Iteration 3     ○○●●●                   5 Free          1 Free                          Node is available.
[EV Node 1]     Iteration 3     ●●○●●                   4 Full          0 Free          2 Free          Node is available.
[EV Node 7]     Iteration 3     ●●●●●   4 Free                          6 Free          8 Free          Node Full but neighbor is free.
[EV Node 5]     Iteration 3     ○●●●●   2 Free          8 Free          4 Full                          Node is available.
[EV Node 4]     Iteration 3     ●●●●●   1 Free          7 Full          3 Free          5 Free          Node Full but neighbor is free.
[EV Node 3]     Iteration 3     ●●●○●   0 Free          6 Full                          4 Full          Node is available.
[EV Node 0]     Iteration 3     ●●●○●                   3 Free                          1 Free          Node is available.
[EV Node 6]     Iteration 3     ●●●●●   3 Free                                                  7 Full          Node Full but neighbor is free.
[Base Node] 3 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 8]     Iteration 4     ●●●●○   5 Free                          7 Full                          Node is available.
[EV Node 3]     Iteration 4     ●●●○●   0 Free          6 Free                                  4 Full          Node is available.
[EV Node 2]     Iteration 4     ●○●●●                   5 Free          1 Free                          Node is available.
[EV Node 1]     Iteration 4     ●●●●●                   4 Full          0 Free          2 Free          Node Full but neighbor is free.
[EV Node 5]     Iteration 4     ○●●●●   2 Free          8 Free          4 Full                          Node is available.
[EV Node 4]     Iteration 4     ●●●●●   1 Full          7 Full          3 Free          5 Free          Node Full but neighbor is free.
[EV Node 7]     Iteration 4     ●●●●●   4 Full                          6 Full          8 Free          Node Full but neighbor is free.
[EV Node 0]     Iteration 4     ●●●●●                   3 Free                          1 Full          Node Full but neighbor is free.
[EV Node 6]     Iteration 4     ●●●●●   3 Free                                                  7 Full          Node Full but neighbor is free.
[Base Node] 2 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 5]     Iteration 5     ○●●●●   2 Free          8 Free          4 Full                          Node is available.
[EV Node 7]     Iteration 5     ●●●●●   4 Full                          6 Full          8 Free          Node Full but neighbor is free.
[EV Node 4]     Iteration 5     ●●●●●   1 Full          7 Full          3 Full          5 Free          Node Full but neighbor is free.
[EV Node 1]     Iteration 5     ●●●●●                   4 Full          0 Full          2 Free          Node Full but neighbor is free.
[EV Node 2]     Iteration 5     ●●●●●                   5 Free          1 Full                          Node Full but neighbor is free.
[EV Node 8]     Iteration 5     ●●●●●   5 Free                          7 Full                          Node Full but neighbor is free.
[EV Node 0]     Iteration 5     ●●●●●                   3 Full                          1 Full          Area Full and  the nearest available node is 5.
[EV Node 3]     Iteration 5     ●●●●●   0 Full          6 Full                          4 Full          Area Full and  the nearest available node is 5.
[Base Node] 1 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 6]     Iteration 5     ●●●●●   3 Full                                                  7 Full          Area Full and  the nearest available node is 5.
[EV Node 2]     Iteration 6     ●●●●●                   5 Free          1 Full                          Node Full but neighbor is free.
[EV Node 8]     Iteration 6     ●●●●●   5 Free                          7 Full                          Node Full but neighbor is free.
[EV Node 0]     Iteration 6     ●●●●●                   3 Free                          1 Free          Node Full but neighbor is free.
[EV Node 5]     Iteration 6     ○●●●●   2 Full          8 Full          4 Full                          Node is available.
[EV Node 4]     Iteration 6     ●●●●●   1 Free          7 Full          3 Full          5 Free          Node Full but neighbor is free.
[EV Node 3]     Iteration 6     ●●●●●   0 Full          6 Full                          4 Full          Area Full and  the nearest available node is 5.
[Base Node] 0 iteration(s) left

Node            Iteration       Ports   Up Neighbor     Down Neighbor   Left Neighbor   Right Neighbor  Node status
[EV Node 6]     Iteration 6     ●●●●●   3 Full                                                  7 Full          Area Full and  the nearest available node is 5.
[EV Node 7]     Iteration 6     ●●●●●   4 Full                                          6 Full          8 Full          Area Full and  the nearest available node is 5.
[EV Node 1]     Iteration 6     ●●●●●                   4 Full          0 Full          2 Full          Area Full and  the nearest available node is 5.
[EV Node 5]     Iteration 7     ○●●●●   2 Full          8 Full          4 Full                          Node is available.
[EV Node 2]     Iteration 7     ●●●●●                   5 Free          1 Full                          Node Full but neighbor is free.
[EV Node 8]     Iteration 7     ●●●●●   5 Free                          7 Full                          Node Full but neighbor is free.
[EV Node 4]     Iteration 7     ●●●●●   1 Full          7 Full          3 Full          5 Free          Node Full but neighbor is free.
[EV Node 6]     Iteration 7     ●●●●●   3 Full                                                  7 Full          Area Full and  the nearest available node is 5.
[EV Node 0]     Iteration 7     ●●●●●                   3 Full                          1 Full          Area Full and  the nearest available node is 5.
[EV Node 1]     Iteration 7     ●●●●●                   4 Full          0 Full          2 Full          Area Full and  the nearest available node is 5.
[EV Node 3]     Iteration 7     ●●●●●   0 Full          6 Full                          4 Full          Area Full and  the nearest available node is 5.
[Base Node] Terminating...
Process 9: worst iteration time taken:2.000507, total time taken:15.104227
[EV Node 7]     Iteration 7     ●●●●●   4 Full                                          6 Full          8 Full          Area Full and  the nearest available node is 5.
[EV Node 1] Terminated.
Process 1: worst iteration time taken:4.000176, total time taken:16.139467
[EV Node 5] Terminated.
Process 5: worst iteration time taken:2.000208, total time taken:16.130420
[EV Node 3] Terminated.
Process 3: worst iteration time taken:4.000216, total time taken:16.135258
[EV Node 7] Terminated.
[EV Node 2] Terminated.
Process 2: worst iteration time taken:2.000214, total time taken:16.136042
[EV Node 4] Terminated.
[EV Node 6] Terminated.
Process 6: worst iteration time taken:4.000243, total time taken:16.126882
[EV Node 0] Terminated.
Process 0: worst iteration time taken:4.000236, total time taken:16.140132
[EV Node 8] Terminated.
Process 8: worst iteration time taken:2.000291, total time taken:16.123809
Process 4: worst iteration time taken:4.000074, total time taken:16.132688
Process 7: worst iteration time taken:4.000204, total time taken:16.125312
[json0041@student-caas-headnode AS2]$
```

Further explanation

Minimizing the MPI Send usage

The algorithm has tried to minimize the usage of MPI send but have found that report base when the node is NODE_FULL but not AREA_FULL is necessary.

Take the bottom scenario as example, base node will only know the neighbour of (3,3) is full when (3,3) is AREA_FULL. The base node knows these neighbours are full and they all have at least one free neighbour for each of them but will have no idea which nodes are exactly free. Do another MPI send to confirm the neighbours of neighbours would be less efficient.

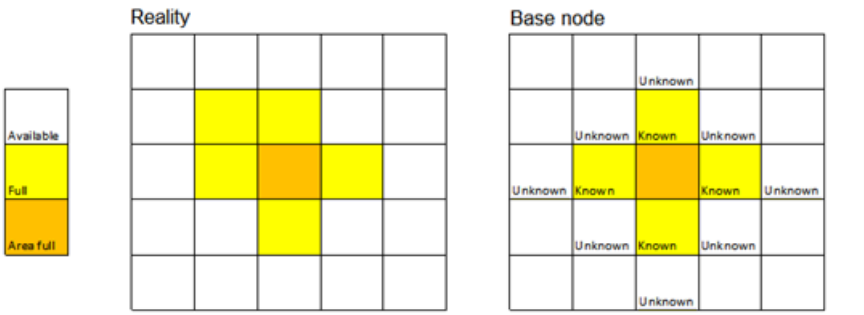


Fig.7: What base node can know if only node (3,3) report area full

MPI Send tag

The send tag set as following:

$$(TAG\ TYPE\ +\ rank\ number) \times iteration$$

In this case, the tag in the program is unique between different type of message & different ranks & different iteration.

The additional while loop used

When the AREA_FULL node sends the request, it needs to block the receive action underneath until the base node confirm the send action, so it is best to use Ssend here. However, the in rare cases (especially when too many nodes in the network), in the last iteration of the program, the base node terminates too fast before the send action from EV node being sent.

The while loop will keep test the isend request until base node received, but it will check whether the base node sent a bcast as well to make sure that base node did not quit or enter a new iteration. It will give up and halt after 2*WAIT_INTERVAL time.

Reference

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