FINAL DOCUMENTATION FOR WPCN-UAV PAPER

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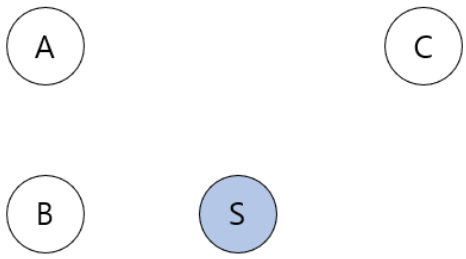
1. newGeneticDeviceVisitAI.py

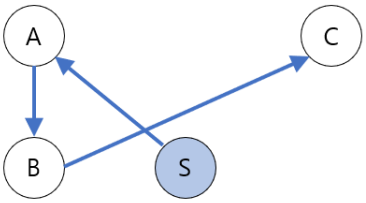
1-1. **Goal:** For each cluster, to determine whether the brute-force search of the optimal path for the movement of UAV

1-2. Brute-force search of optimal path:

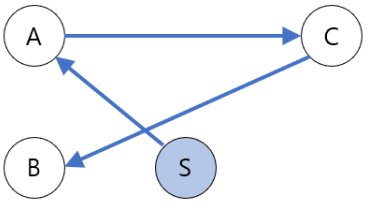


The picture on the left describes the start location of UAV **(S)** and the fixed locations of each device **(A, B and C).**

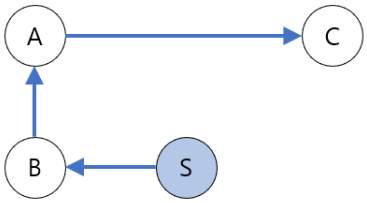
When doing Brute-force search, we check the total length of path when the UAV moves **"S-A-B-C", "S-A-C-B", ..., "S-C-B-A"**.



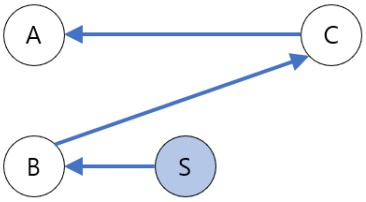
S-A-B-C : distance **4.6**



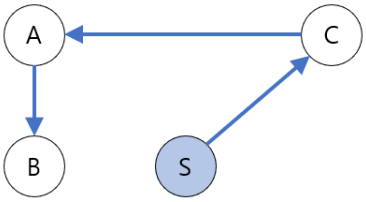
S-A-C-B : distance **5.6**



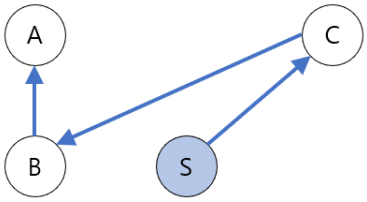
S-B-A-C : distance **4.0 (OPTIMAL)**



S-B-C-A : distance **5.2**



S-C-A-B : distance **4.4**



S-C-B-A : distance **4.6**

The figure above is the result of our Brute-force search. For **N** devices, we should search for **N!** cases. In the situation above, we searched for **3! = 6** cases and we got the result that **the optimal path with the shortest total Euclidean distance is S-B-A-C** whose **distance is 4.0.**

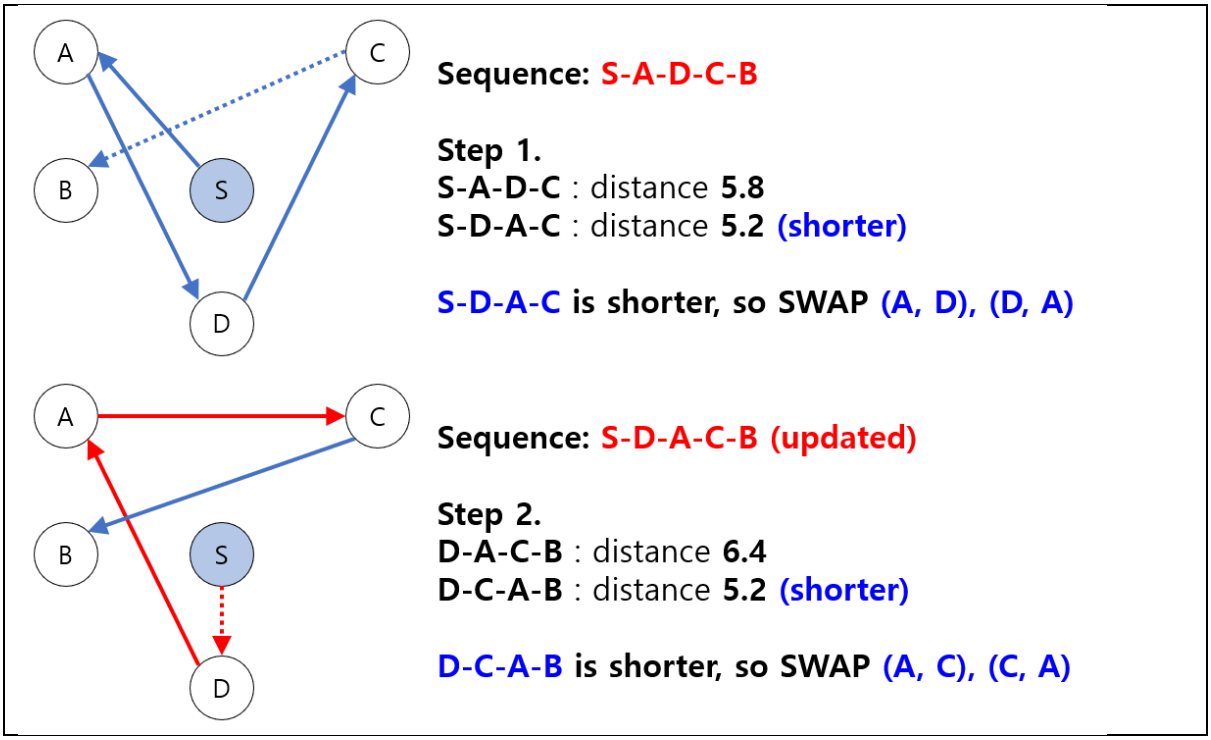
1-3. Swap-basic search:

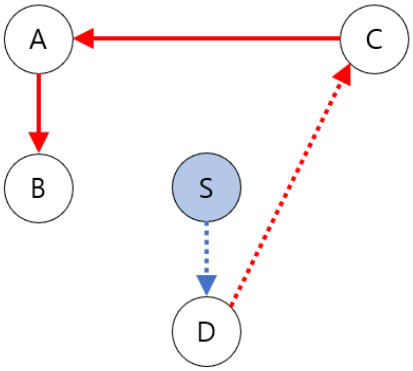
Swap-basic search is the method to find the shortest total Euclidean distance with swapping the device visit sequence. **(suppose that the number of device is 8)**

With start location of UAV **S**, device **d1, d2, ..., d8** where **CURRENT (updated)** visit sequence is **S->d1->d2->...->d8**

While True: // until convergence
    For each **case** in **{d1, d2, d3}, {d1, d2, d3, d4}, ..., {d4, d5, d6, d7}, {d5, d6, d7, d8}, {d6, d7, d8}** // total (8 – 1 = 7) cases
        If **d1 in case** and **len(case) == 3:** // include start
            swapCondition = (S->**d2->d1**->d3) is shorter than (S->**d1->d2**->d3)
            if swapCondition is True:
                (d1, d2) = (d2, d1)
        else if **d8 in case** and **len(case) == 3:** // include end
            swapCondition = (d6->**d8->d7**) is shorter than (d6->**d7->d8**)
            if swapCondition is True:
                (d7, d8) = (d8, d7)
        else: // other cases
            swapCondition = (case[0]->**case[2]->case[1]**->case[3]) is shorter than (case[0]->**case[1]->case[2]**->case[3])
            if swapCondition is True:
                (case[1], case[2]) = (case[2], case[1])
    Terminate if **do not updated** // terminate when reached convergence

For example,

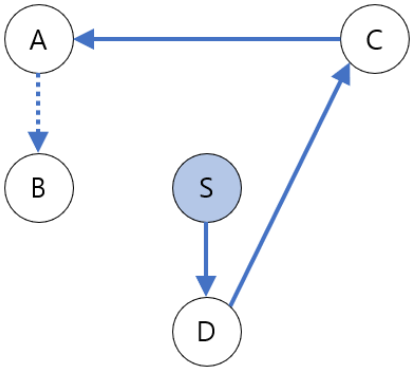




Sequence: S-D-C-A-B (updated)

Step 3.
C-A-B : distance **3.0** **(shorter)**
C-B-A : distance **3.2**

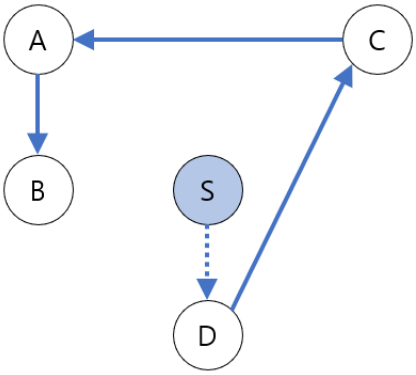
C-A-B is shorter, so DO NOT SWAP



Sequence: S-D-C-A-B

Step 4.
S-D-C-A : distance **5.2** **(shorter)**
S-C-D-A : distance **5.8**

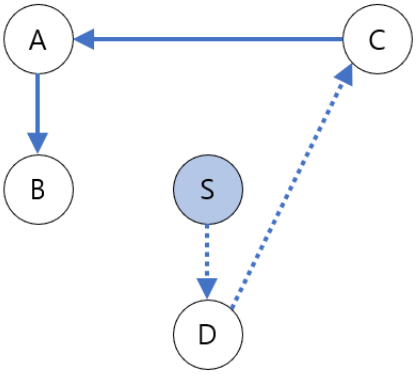
S-D-C-A is shorter, so DO NOT SWAP



Sequence: S-D-C-A-B

Step 5.
D-C-A-B : distance **5.2** **(shorter)**
D-A-C-B : distance **6.4**

D-C-A-B is shorter, so DO NOT SWAP



Sequence: S-D-C-A-B

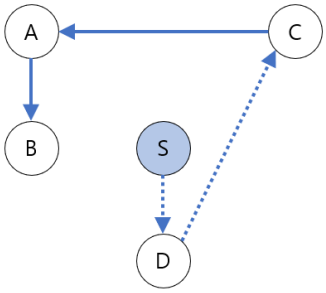
Step 6.
C-A-B : distance **3.0** **(shorter)**
C-B-A : distance **3.2**

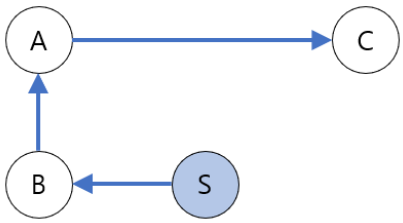
C-A-B is shorter, so DO NOT SWAP
Terminate because NO UPDATE

1st iteration : **Step 1 ~ Step 3**
2nd iteration : **Step 4 ~ Step 6**

1-4. Deep Learning Approach

Use Deep Learning to **determine whether the Brute-force search is needed**:

<table>
<tr><td>Original data</td><td>Movement S->d1->d2->...->d8</td></tr>
<tr><td>Input data</td><td>For each segment of the movement S->d1, d1->d2, ..., d7->d8,
1. x distance of the movement
2. y distance of the movement
For each segment of the movement S->d1, d1->d2, ..., d7->d8,
3. sin(A) where A is the angle of the movement
4. cos(A) where A is the angle of the movement
5. Euclidean distance of the movement</td></tr>
<tr><td>Output data</td><td>$$\min\left(1.0, \log_{1.75}\frac{D_{SB}}{D_{BF}}\right) \rightarrow always\ between\ 0.0\ and\ 1.0$$
Where D_{SB} is the total length of the movement path after applying Swap-Basic method, and D_{BF} is the total length of the movement path of the optimal movement derived by Brute-force search
(NOTE: $D_{SB} \geq D_{BF}$ is always true because D_{BF} is the optimal distance)
 

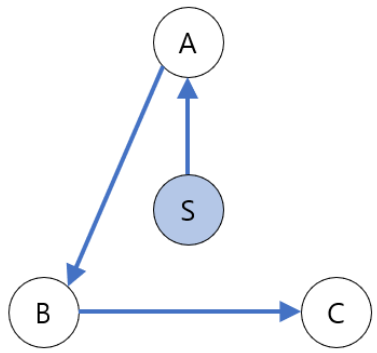
Sequence: S-D-C-A-B
Step 6.
C-A-B : distance 3.0 (shorter)
C-B-A : distance 3.2
C-A-B is shorter, so DO NOT SWAP
Terminate because NO UPDATE
In the situation of 1-3 (the picture above), the movement path of S->D->C->A->B is derived by Swap-Basic method and whose total distance is 6.2, so $D_{SB} = 6.2$
 

In the situation of 1-2, (the picture on the left side) the movement path of S->B->A->C is optimal (derived by Brute-force method) and whose total distance is 4.0, so $D_{BF} = 4.0$
S-B-A-C : distance 4.0 (OPTIMAL)
NOTE: The two cases above are DIFFERENT (so, DO NOT think of 6.2/4.0)</td></tr>
</table>

Suppose that **the start location of the UAV is the CENTROID of all the devices** and **the number of devices is 8**

Main idea (important): Brute-force search is needed if D_{SB}/D_{BF} value is large enough

Example about the input data:



movement path: **S->A->B->C**

location of the start location of UAV **(S)** and each device **(A, B and C)** is,

➔ S (x=**0.0**, y=**0.0**)

➔ A (x=**0.0**, y=**+1.0**)

➔ B (x=**-0.866**, y=**-0.5**)

➔ C (x=**+0.866**, y=**-0.5**)

For each segment **S->A, A->B and B->C**,

	S->A	A->B	B->C
X distance	X1 = 0.0	X2 = -0.866	X3 = +1.732
Y distance	Y1 = +1.0	Y2 = -1.5	Y3 = 0.0
Angle A	90 degree	240 degree	0 degree
Sin(A)	Sin1 = +1.0	Sin2 = -0.866	Sin3 = 0.0
Cos(A)	Cos1 = 0.0	Cos2 = -0.5	Cos3 = +1.0
Euclidean distance	Dist1 = 1.0	Dist2 = 1.732	Dist3 = 1.732

The form of the input data is,

(X1, Y1, X2, Y2, X3, Y3, sin1, cos1, dist1, sin2, cos2, dist2, sin3, cos3, dist3)

So, the input data for this case is,

(0.0, +1.0, -0.866, -1.5, +1.732, 0.0, +1.0, 0.0, +1.0, -0.866, -0.5, +1.732, 0.0, +1.0, +1.732)

1-5. Model Genetation using the idea of 1-4

1. Create **16,000** cases of the clusters (refer to variable **'times'** of **newGeneticDeviceVisitAI.py**)

➔ The number of devices in the cluster is as the table below

```
if __name__ == '__main__':

    # numpy setting
    np.set_printoptions(edgeitems=20, linewidth=200)

    input_data      = []
    output_data     = []
    times           = 16000
    deviceCountList = []
```

2. Do Deep Learning for these cases using **12,960 (81%) training data, 1,440 (9%) validation data and 1,600 (10%) test data**
3. The model is generated based on the deep learning result.

The number of devices: **(probability)**

4 devices	5	6	7	8 devices
15%	22%	26%	22%	15%

2. throughputTest_NewGenetic.py

2-1. Configuration

In **settings.txt**, you can modify the variables below:

	description	Default value
width	Width in meter	50
height	Height in meter	50
L	The number of clusters	5
devices	The total number of devices in the all clusters	30
N	Flight period (the number of time slots)	30
iters	The number of iterations	1,200
clusteringAtLeast	cluster contains devices **at least int(this number * average)**	0.67
clusteringAtMost	cluster contains devices **at most int(this number * average)**	1.34

The total number of cases (clusters) to test: **L * iters (default 5 * 1,200 = 6,000)**

In the setting above, the average number of device for each cluster is **(device / L) = 30 / 5 = 6**, so the cluster contains at least **int(0.67 * 6) = 4 devices**, and at most **int(1.34 * 6) = 8 devices**. It is similar to the distribution of the number of the devices in **1-5.**

2-2. Mode Settings

Static (static_swapOnly)	Same as the **static strategy** from Tang et al ➔ Tang J, Song J, Ou Jea. Minimum Throughput Maximization for Multi-UAV Enabled WPCN: A Deep Reinforcement Learning Method. IEEE Access 2020.
Train swap only (train_swapOnly)	Find the **device-visit sequence (movement path)** using **Swap-basic search**, and then visit devices using this sequence. Compute the common throughput based on the sequence.
Train gen visit (train_genVisit)	Find the **device-visit sequence (movement path)** using **Swap-basic search**, and then input the movement path to **the model generated in 1-5**. If the **output value** of the model is **at least (threshold = 0.5)**, then find the device-visit sequence using **Brute-force search** and then visit devices using this sequence. Otherwise, visit devices using the sequence derived by **Swap-basic search**. Compute the common throughput based on the **sequence of device-visit**.

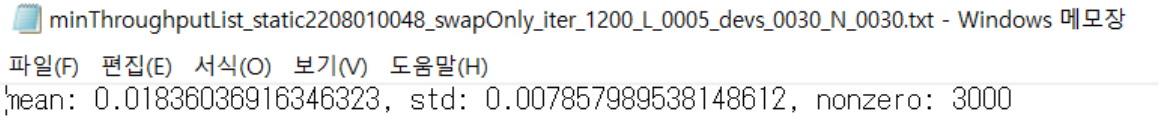
In () is **the prefix of the trajectory image file name**. (**static_swapOnly**_trajectory_iter0000.png for example)

2-3. The number of iterations for each mode

mode	The number of iterations	Total generated clusters when iters=1,200, L=5
Static	iters // 2	(1,200 // 2) * 5 = 3,000
Train swap only	iters	1,200 * 5 = 6,000
Train gen visit	iters	1,200 * 5 = 6,000

2-4. interpretation of the result

Static mode



Time: **2022.08.01 00:48**

Mode: **Static** (refer to **static**2208010048_swapOnly)

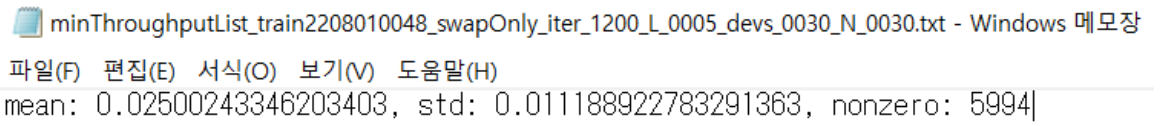
Configurations: iters=**1200**, L=**5**, devices=**30**, N=**30**

Average value of the common throughput: **0.018360**

Standard deviation of the common throughput: **0.007858**

The total number of clusters whose common throughput is non-zero: **3,000** / 3,000 (100.0%)

Train swap only

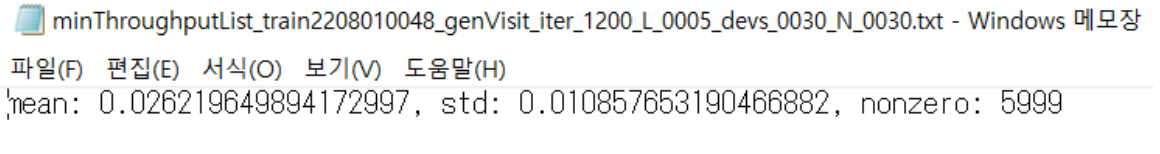


Mode: **Train swap only** (refer to **train**2208010048_**swapOnly**)

Average value, standard deviation of the common throughput: **0.025002, 0.011189**

The total number of clusters whose common throughput is non-zero: **5,994** / 6,000 (99.9%)

Train gen visit



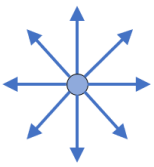
Mode: **Train gen visit** (refer to **train**2208010048_**genVisit**)

Average value, standard deviation of the common throughput: **0.026220, 0.010858**

The total number of clusters whose common throughput is non-zero: **5,999** / 6,000 (99.98%)

3. Actual movement of UAV

3-1. actual movement in each segment



Unit movement is the movement of the UAV in each time slot. Its distance is always **5.0m** and the degree of direction is always one of **0-degree, 45-degree, 90-degree, …, and 315-degree.**

For each unit movement of the movement path **from device A to device B**,

1. Find the direction of the next device
2. Move toward the direction
3. Stop until **moving toward any of the 8 directions increments the distance** between UAV and the device

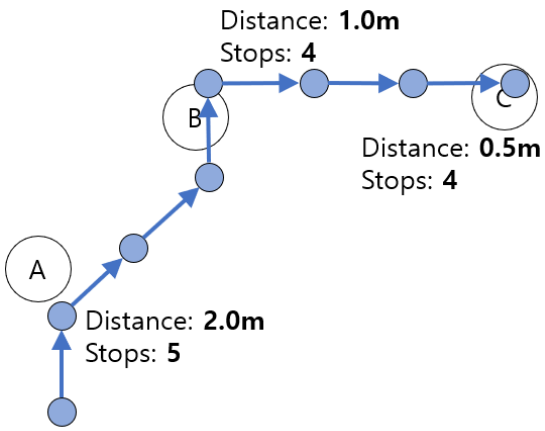
3-2. communication with devices

1. If there are at least 1 device **within 3.125m** of the current UAV location, **communicate with these devices in sequence.**
2. Otherwise, communicate with **the most nearby** device.

3-3. final decision of the movement (with devices d1, d2, …, d8)

1. Compute the actual movement of **S->d1, d1->d2, …, d7->d8**, and assign time slots to the movement.
2. Assign each remaining time slots to the device **(stop UAV for these time slots)**, based on **the distance between the UAV (in proportion to $(distance)^{0.002}$)** and the device when **the UAV is closest to the device**.

For example, if there are **20 time slots** in total and device **A, B and C**,



1. assign **1** time slot to **S->A**, **3** time slots to **A->B**, and **3** time slots to **B->C**, according to **3-1** for each segment **S->A, A->B and B->C.**

2. Assign remaining 13 time slots to stopping at the closest device.

➔ The closest distance between UAV and each device is **2.0m, 1.0m, 0.5m** for device **A, B and C**.

➔ So, assign **5 time slots** to the farthest device A, and **4 time slots** for other devices.

4. Running

4-1. run newGeneticDeviceVisitAI.py first

If you already have Genetic_Visit_AI_model directory with the model, you can skip this stage.

```
D:₩WPCNUAV>python newGeneticDeviceVisitAI.py
D:₩Python37₩lib₩site-packages₩tensorflow_core₩python₩_pywrap_tensorflow_internal.pyd
0


input data (swap)  : [ 1.7474  0.4497 -1.3823  1.304  -1.2989 -2.3533 -0.0068 -0.3983  0.
input data (angle) : [ 0.2492  0.9684  1.8043  0.6862 -0.7274  1.9003 -0.8755 -0.4832  2.
.      0.      0.      0.      0.    ]
dist               : 1.7676 1.4795
0 [1, 0, 2, 3, 4]
1 [4, 3, 2, 0, 1]
```

Otherwise, run **python newGeneticDeviceVisitAI.py**.

4-2. run throughputTest_NewGenetic.py

Run the command **python throughputTest_NewGenetic.py.**