Code Challenge 2021

Build the Sky Highway

March 11, 2021

The **5G ecosystem** is set to be deployed and will completely change life as we know it. Thanks to their management of **antenna assets**, the **TowerCo** is playing the crucial role of ”Neutral Host” into this brave new **connected world**.

The new 5G Antenna Systems (DAS, Small Cells, Massive MIMO) will enable a new range of services, especially for disruptive technologies like AR and VR, remote surgical operations, simultaneous translations, and BVLOS for drones (all services enabling near real-time processing through the edge platform).

What if you were building the sky highway of the future? You would need to know where to correctly place antennas in an urban environment, in line with the project constraints proposed in this problem statement.

The closer the antennas are to users, the more 5G coverage there is and the guarantee of a wide transmission band, which, together with 5G's low latency, makes it possible to provide a new range of services currently unavailable using radio. These services include autonomous driving, massive IoT, and other types of mission-critical services.

Read the problem statement below, work with your team, and develop the algorithm to build the city of the future.

1 Problem statement

You are given the description of a city, represented by a bidimensional grid of width $\mathcal{W}$ and height $\mathcal{H}$.

On this grid, a series of buildings are positioned and your goal is to place the available antennas in the best positions, according to requirements of each building, in order to connect the city in the best way to the **5G ecosystem**.

1.1 Building

A total of $\mathcal{N}$ buildings are already positioned on the grid, each of them in a distinct location and needs connection.

As buildings are of various types also their connection needed can be different, in particular each building characterized by the three factors:

- Its position on the grid.
- **Latency weight**: how important is the latency for the building.
- **Connection speed weight**: how important is the connection speed for the building.

1.2 Antenna

A total of $\mathcal{M}$ of antennas are available to be freely placed on the grid to give connectivity to the neighborhood.

As also antennas can be of various types, each of them is characterized by two factors:

- **Range**: the distance that the antenna signal can reach.
- **Connection speed**: the connection speed provided to the building connected to it.

Refer to the scoring section for the details.

Note that an antennas will provide the same ammount of connection speed to all the buildings connected to it, regardless of the number of buildings.

1.3 Reward

As one of the goal of the **5G ecosystem** is to reduce the digital divide, a reward of $\mathcal{R}$ points will be assigned to the final score only if all the buildings are connected to at least one antenna.

2 Input format

Input data will be provided in a text file in plain ASCII format and lines ending with a single $\backslash n$ character.

The first line of the input will contains two space-separated integer numbers:

- $\mathcal{W}$: the width of the grid.
- $\mathcal{H}$: the height of the grid.

The second line of the input will contains three space-separated integer numbers:

- $\mathcal{N}$: the number of buildings present in the grid.
- $\mathcal{M}$: the number of available antennas that can be placed in the grid.
- $\mathcal{R}$: the reward assigned if all the buildings are connected to the network.

The next $\mathcal{N}$ lines contains four space-separated integer numbers each:

- $B_X[i]$: the x coordinate of the i^{th} building.
- $B_Y[i]$: the y coordinate of the i^{th} building.
- $B_L[i]$: the latency weight of the i^{th} building.
- $B_C[i]$: the connection speed weight of the i^{th} building.

The next $\mathcal{M}$ lines contains two space-separated integer numbers each:

- $A_R[i]$: the range of the i^{th} antenna.
- $A_C[i]$: the connection speed of the i^{th} antenna.

3 Output format

The output data has to be saved into a plain-text ASCII file.

The first line of the output contains one integer number:

- $\mathcal{M}'$: the number of antennas placed in the grid

The next $\mathcal{M}'$ lines contains two space-separated integer numbers:

- id_i: the id of the i^{th} antenna to be placed
- $A_X[id_i]$: the x coordinate of the i^{th} antenna
- $A_Y[id_i]$: the y coordinate of the i^{th} antenna

The antenna identifier is meant as the 0-based index of the antennas available from the input data.

4 Constraints

The input data is subject to these constraints:

- Grid width: $10 \le \mathcal{W} \le 6\,000$.
- Grid height: $10 \le \mathcal{H} \le 6\,000$.
- Number of buildings: $1 \le \mathcal{N} \le 350\,000$.
- Number of antennas: $1 \le \mathcal{M} \le 60\,000$.
- Reward: $1 \le \mathcal{R} \le 200\,000\,000$.
- Latency weight: $0 \le B_L[i] \le 100$ $(0 \le i < \mathcal{N})$.
- Connection speed weight: $0 \le B_C[i] \le 100$ $(0 \le i < \mathcal{N})$.
- Antenna range: $0 \le A_R[i] \le 6\,000$ $(0 \le i < \mathcal{M})$.
- Antenna connection speed: $1 \le B_C[i] \le 10\,000$ $(0 \le i < \mathcal{M})$.
- Coordinates are 0-based: $0 \le x < \mathcal{W}$ and $0 \le y < \mathcal{H}$.
- id of buildings and antennas are 0-based.
- All the buildings coordinates are valid and unique.

An output file is consider valid if these constraints are satisfied:

- $1 \le \mathcal{M}' \le \mathcal{M}$.
- All the antennas identifier are valid and unique.

Further clarification:

- An antenna can be placed in the same cell of a building.
- Two antennas cannot be placed in the same cell.

5 Scoring

The scoring consists of two parts: the building scores and the reward:

5.1 Building score

Given a building b, let $r(b)$ the list of the reachable antenna indexes:

$$r(b) = \{a \mid dist(a, b) \leq A_R[a]\} \tag{1}$$

The distance $dist(a, b)$ between an antenna a and a building b is defined as the manhattan distance between the two coordinate.

The score $s(a, b)$ for a building b connect to an antenna a is defined by:

$$s(a, b) = B_C[b] \times A_C[a] - B_L[b] \times dist(b, a) \tag{2}$$

A building b will then connect to the antenna that maximize the score $s(a, b)$:

$$c(b) = \max_{a \in r(b)} s(a, b) \tag{3}$$

The score $s(b)$ of a building b is thus:

$$s(b) = s(c(b), b) \tag{4}$$

If no antennas are reachable ($r(b) = \emptyset$) then $s(b) = 0$.

5.2 Reward

The reward is assigned if and only if all the buildings are connect to an antenna. Thus:

$$reward(x) = \begin{cases} \mathcal{R} & \text{if } |\{b \mid r(b) \neq \emptyset\}| = \mathcal{N} \\ 0 & otherwise \end{cases} \tag{5}$$

5.3 Total score

The total score of a valid output is calculated as the sum of all the building scores and the reward:

$$score = \sum_{0 \leq i < \mathcal{N}} s(i) + reward \tag{6}$$

6 Example

6.1 input file

```
15 10
5 4 100
0 7 3 20
12 2 2 14
2 4 1 32
10 7 4 44
11 8 3 23
2 100
4 10
1 50
2 40
```

6.2 output file

```
4
0 12 3
1 7 6
2 11 7
3 2 4
```

6.3 Scoring

- Building 0 (0, 7) is NOT connected

- Building 1 (12, 2) is connected to antenna 0 (12, 3)

  - Distance: 1
  - Connection speed: 100
  - Connection score: 14 * 100 = 1400
  - Latency score: 2 * 1 = 2
  - Score: 1398

- Building 2 (2, 4) is connected to antenna 3 (2, 4)

  - Distance: 0
  - Connection speed: 40
  - Connection score: 32 * 40 = 1280
  - Latency score: 1 * 0 = 0
  - Score: 1280

- Building 3 (10, 7) is connected to antenna 2 (11, 7)

  - Distance: 1
  - Connection speed: 50
  - Connection score: 44 * 50 = 2200
  - Latency score: 4 * 1 = 4
  - Score: 2196

- Building 4 (11, 8) is connected to antenna 2 (11, 7)

  - Distance: 1
  - Connection speed: 50
  - Connection score: 23 * 50 = 1150
  - Latency score: 3 * 1 = 3
  - Score: 1147

We have thus:

- Connected building = 4 out of 5
- Assigned reward = 0
- Total score = 1398 + 1280 + 2196 + 1147 = 6021

6.4 Visualization