Drone Delivery Optimization

Drone delivery has gained immense popularity in recent years, with more and more companies adopting this technology to make their logistics operations more efficient. One of the critical challenges in drone delivery is to optimize the delivery routes. In our project, we use Mixed-Integer Linear programming to find optimal trajectories for the drones that ensures fast delivery times and minimum distance

Optimal Battery Charging Location

Problem Setting (I) :-

- ❑ Given a grid with obstacles and a fixed number of battery charging stations, where do you place the battery charging stations, such that the number of traversable grid points is maximised.

Mathematical Model :-

Objective Function :-

The grid points that can be traversed should be maximum.

$$max(\Sigma_i \Sigma_j y_{ij})$$

where, $y_{ij} := \begin{cases} 1 & ;if\ (i,j)\ is\ traversed \\ 0 & ;\ \ otherwise \end{cases}$

Constraints :-

- ❑ For all blocked grid points (i,j):-

$$x_{ij} = 0$$

where, x_{ij} = location of charging stations

- ❑ For all grid points (i,j):-

$$\Sigma_i \Sigma_j x_{ij} \le k$$

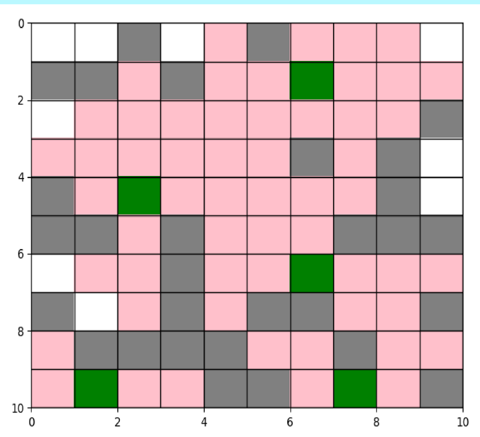
where, k is the maximum number of charging stations

- ❑ For all grid points (i,j):-

$$\Sigma_p \Sigma_q x_{pq} \ge y_{ij} \quad s.t. \quad distance\big((i,j),(p,q)\big) \le d$$

where, d is the distance that can be traversed in a single battery charge and distance matrix is a parameter representing distance between any two grid points using Floyd-Warshall Algorithm.

Results :-



- ➢ d = 3; k = 5;
- location of charging stations
- blocked grid cells
- grid cells that can be traversed
- grid cells that cannot be traversed

Problem Setting (II) :-

- ❑ Given a grid with obstacles, where do you place the battery charging stations such that all grid points are traversable and number of battery charging stations is minimised.

Mathematical Model :-

Objective Function :-

The number of charging stations should be minimum

$$min(\Sigma_i \Sigma_j x_{ij})$$

where, x_{ij} = grid cells where charging stations are present

Constraints :-

- ❑ For all blocked grid points (i,j):-

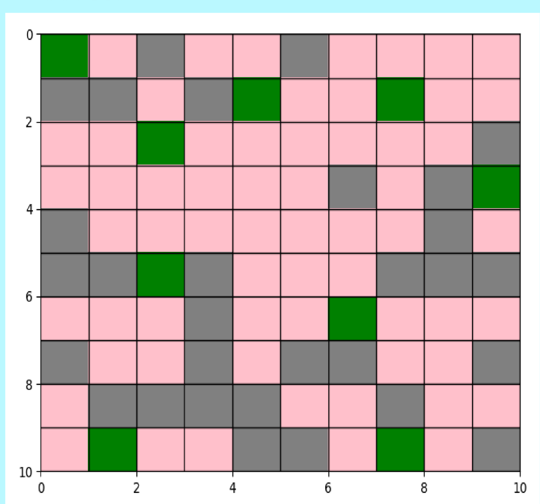
$$x_{ij} = 0$$

- ❑ For all unblocked grid points (i,j):-

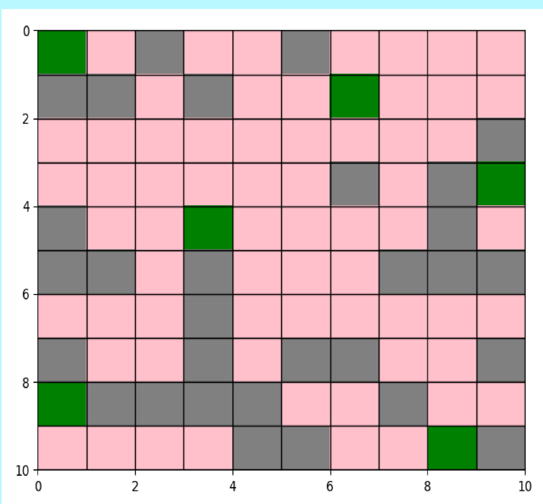
$$\Sigma_p \Sigma_q x_{pq} \ge 1 \quad s.t. \quad distance\big((i,j),(p,q)\big) \le d$$

where, distance and d are defined the same as above

Results :-



for d = 3, no. of charging stations = 9



for d = 5, no. of charging stations = 6

Optimal Drone Trajectory

Problem Setting :-

- ❑ Given a grid with obstacles and battery charging stations, find the optimal trajectory of the drone that minimises travelling cost (i.e., minimises distance).

Mathematical Model :-

Objective Function :-

- ❑ Objective is to minimize the total travelling cost of the drone

$$min(\Sigma_{i,j,k,l} distance\big((i,j),(k,l)\big) * visited(i,j) * visited(k,l))$$

where:

- $distance\big((i,j),(k,l)\big)$:= distance between node (i,j) & (k,l)
- $visited$ encapsulates the state of the grid := $\begin{cases} 1\ ;if\ grid\ point\ (i,j)\ is\ visited \\ 0 \quad ;otherwise \end{cases}$

Constraints :-

- ❑ Path connectedness:

For all grid points (i,j)

$$\sum_{k,l} edge(i,j,k,l) := \begin{cases} 1 * visited(i,j) & ;if\ (i,j)\ is\ initial\ or\ final\ point \\ 2 * visited(i,j) & ;\ \ otherwise \end{cases}$$

where 4D-matrix $edge$ captures the active edges from node (i,j).

- ❑ Battery Constraint:

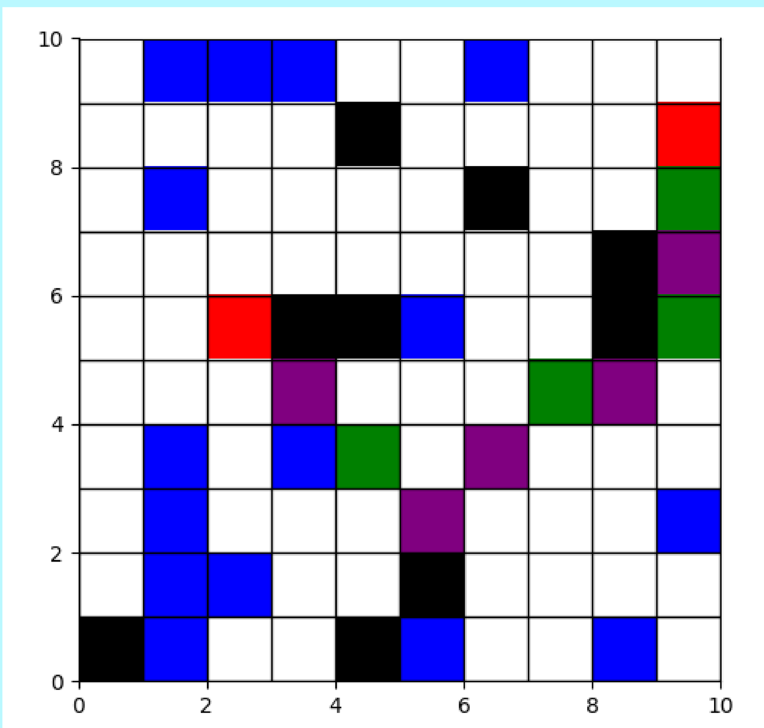
For all grid points (i,j) that are visited

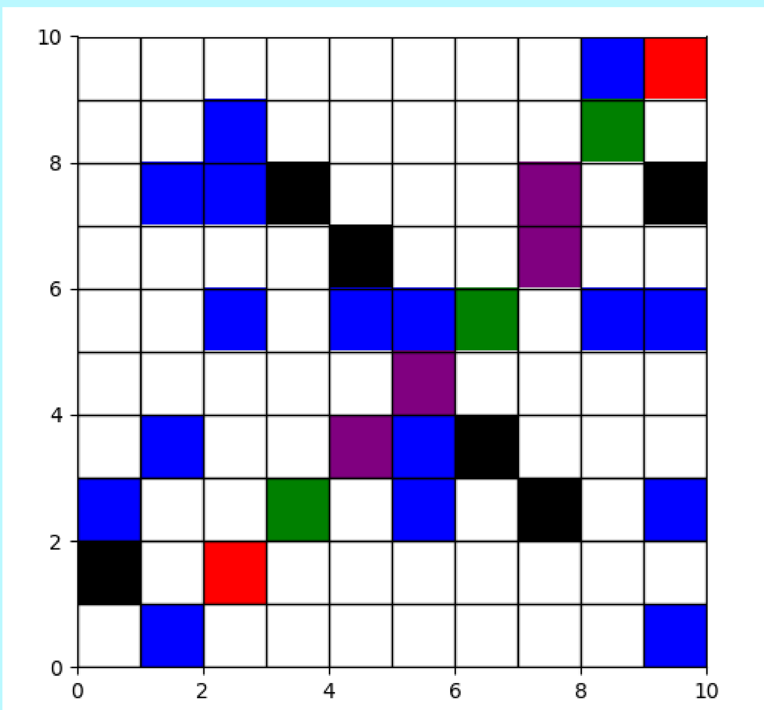
$$\sum_{p,q} battery\_visited(p,q) = 2$$

where $battery\_visited$ represents the locations of battery stations that are visited & (p,q) are the 5x5 neighbours of (i,j).

Results :-

- nodes that aren't visited
- source and destination nodes
- battery charging stations
- blocked nodes
- nodes that are visited
- visited charging stations





Optimal Scheduling

Problem Setting :-

- ❑ Given 2 drones and 2 warehouses and x delivery locations each having demand x_i, find the optimal trajectory of both the drones such that travelling cost and total delivery time is minimised.
- ❑ Assumptions: i) Both drones start from different warehouses.
  ii) A drone can carry only 1 package at a time.
  iii) Warehouses can supply any number of packages.

Mathematical Model :-

Objective Function :-

$$\min(0.7 * net\ distance\ travelled + 0.3 * \sum(time\ taken\ by\ each\ drone\ to\ finish\ it's\ job))$$

Constraints :-

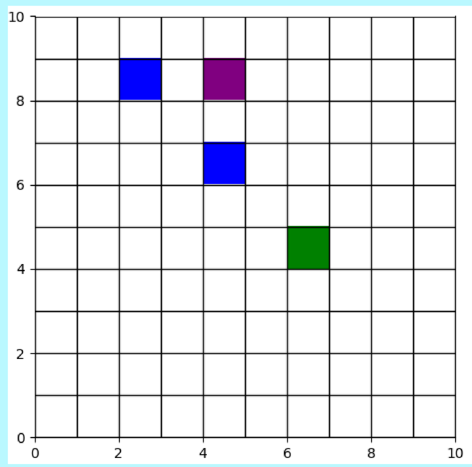
- ❑ Collision avoidance for both the drones:

For all grid points (i,j) and time t :-

$$nodes(1,i,j,t) * nodes(2,i,j,t) = 0$$

- ❑ Demand satisfaction at each delivery location.
- ❑ Supply from warehouse should equal net demand from all delivery locations

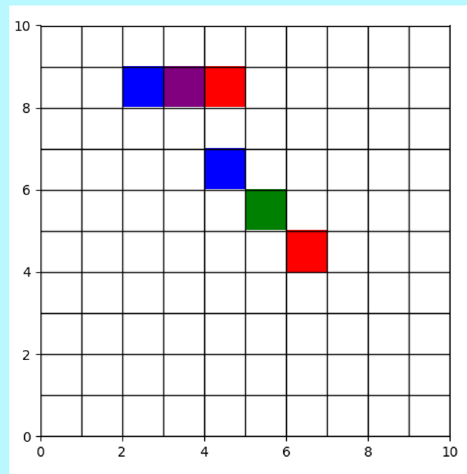
Results :-



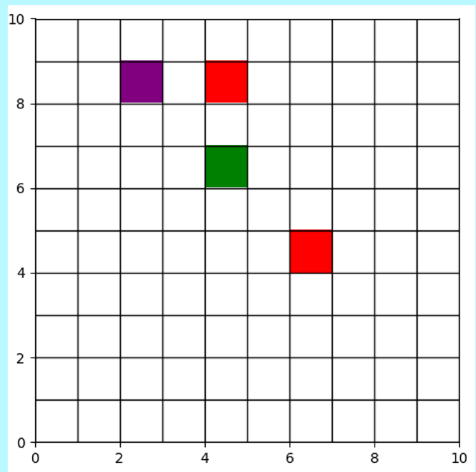
time stamp - 0

- nodes that aren't visited
- warehouse location
- delivery location
- 1st drone
- 2nd drone

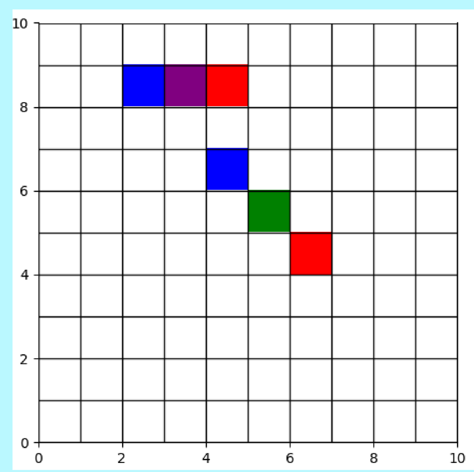
These grids show the path taken by the two drones at different time stamps



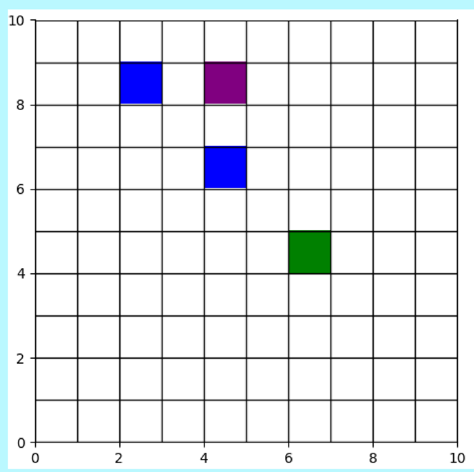
time stamp - 1



time stamp - 2



time stamp - 3



time stamp - 4

Future Work :-

- ❑ Testing our formulation over a real geographical area by modelling it as a grid to assess the formulation for real life feasibility and robustness of algorithm.
- ❑ Exploration of dynamic routing algorithms to optimize delivery routes in real-time based on changing conditions, such as weather or traffic.
- ❑ Development of more sophisticated obstacle detection and avoidance systems to improve the safety and reliability of drone deliveries.
- ❑ Integration of machine learning models to predict demand patterns and adjust delivery schedules accordingly, ensuring timely and efficient delivery.

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