Optimal Multi-Robot Path Planning for Trash Pick and Drop in Hospitals

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Motivation

MIT Robot Gardener

Cucumber Harvester

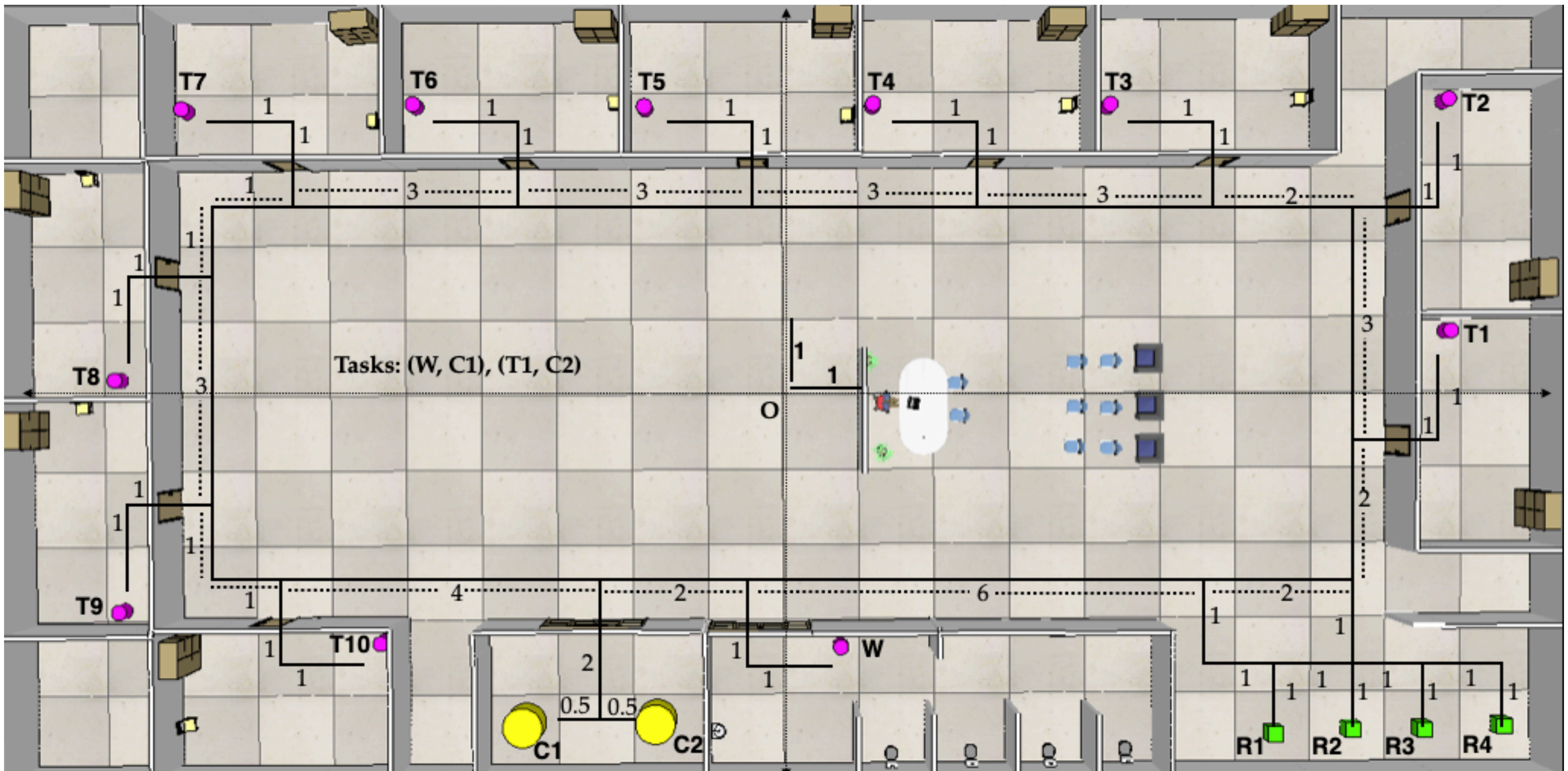
Spray Robot

Mail Delivery Robot

Waste Removal Robot

Waste Removal Robot

Environment



Hospital Environment

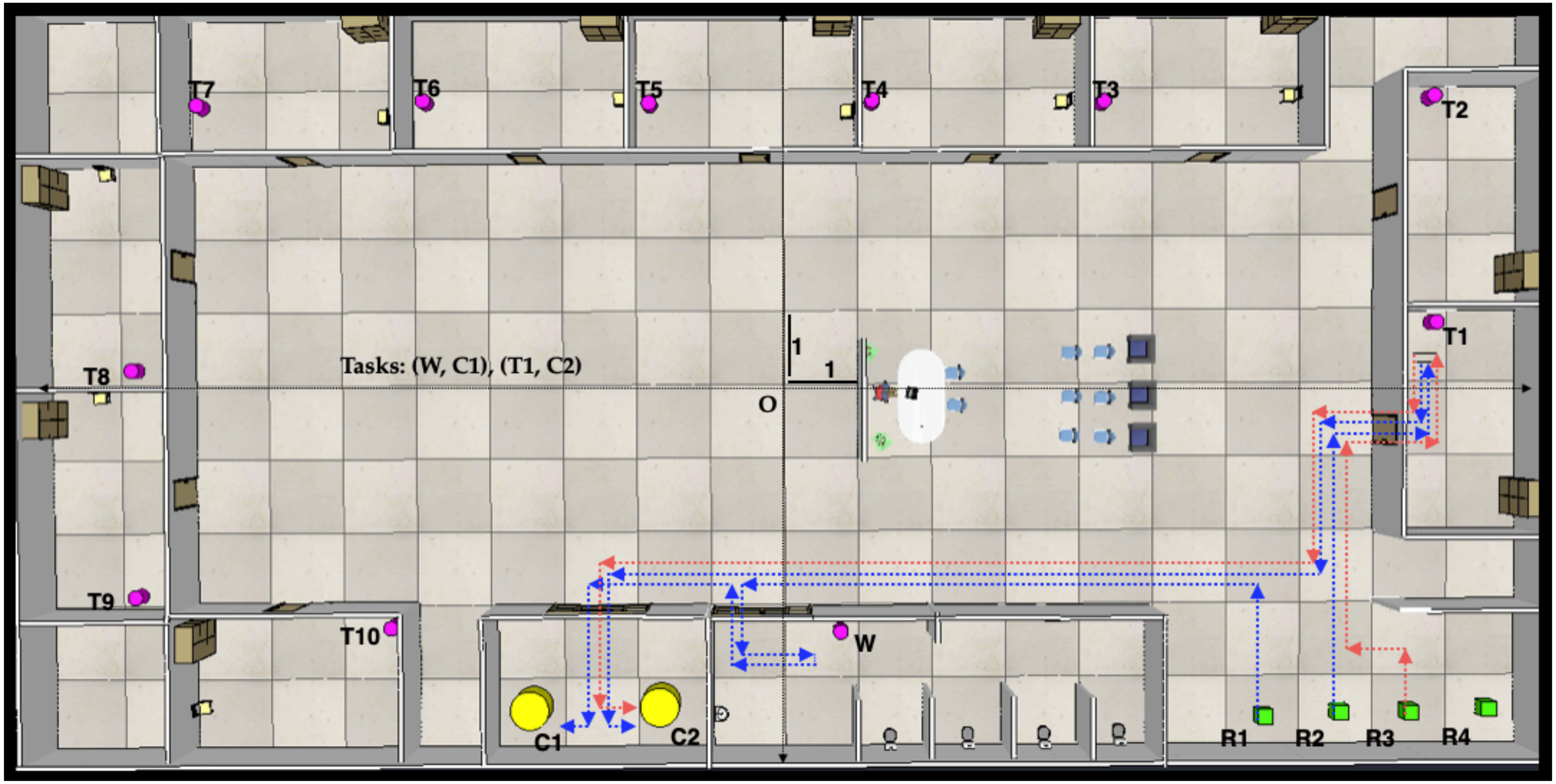
Environment: *consists of the following:*

- *A set of robots' initial location;*
- *A set of all trash bags' location;*
- *A set of all big containers' location;*
- *A set of valid line segments with their length;*

Task: *consists of the following:*

- *A trash bag's location;*
- *A big container's location;*

Pick and Drop Problem

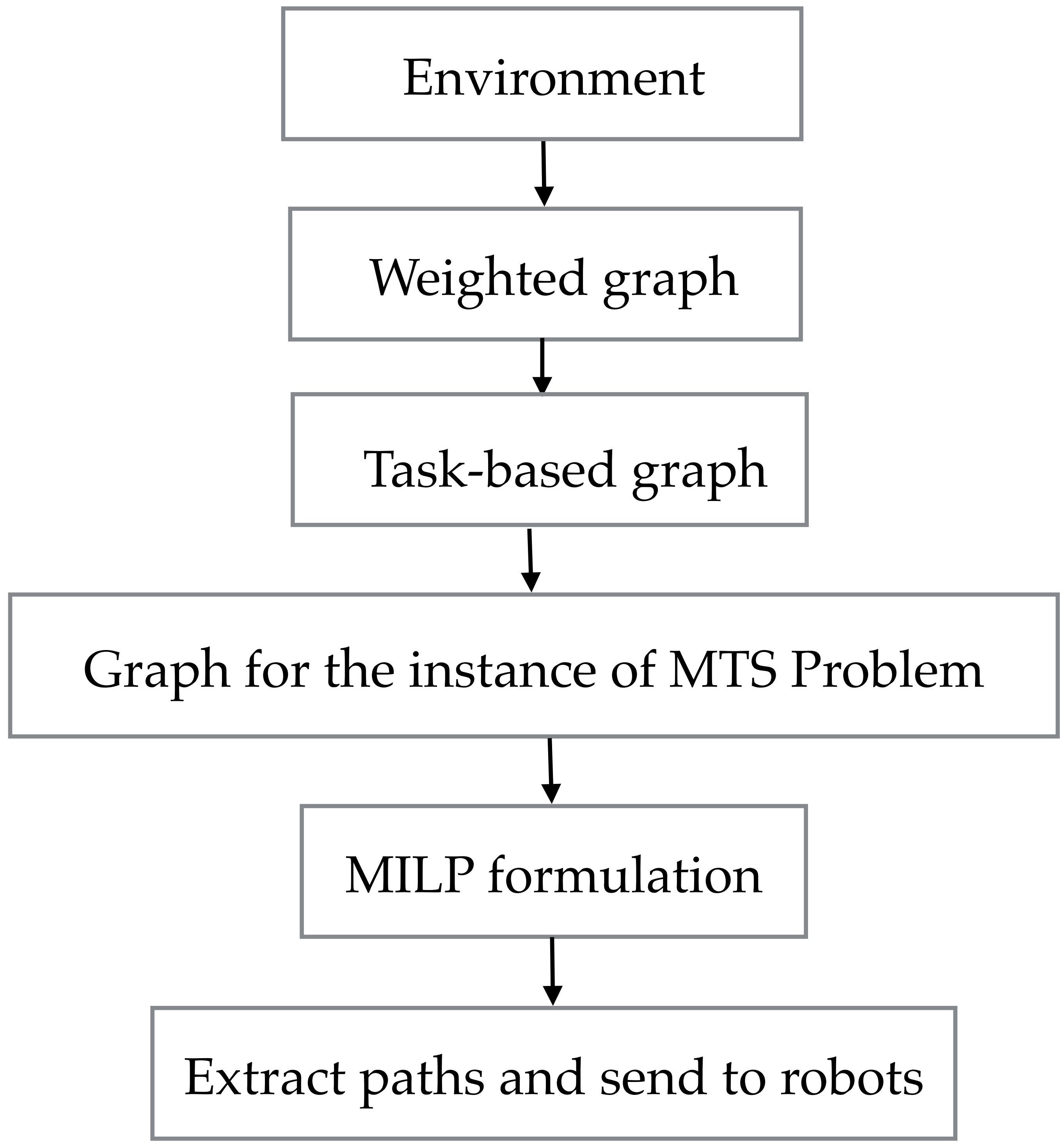


Hospital Environment

Problem: *Find a plan for the robots such that*

- *all pick and drop tasks have been completed*
- *the total distance (time, energy) travelled is minimized*

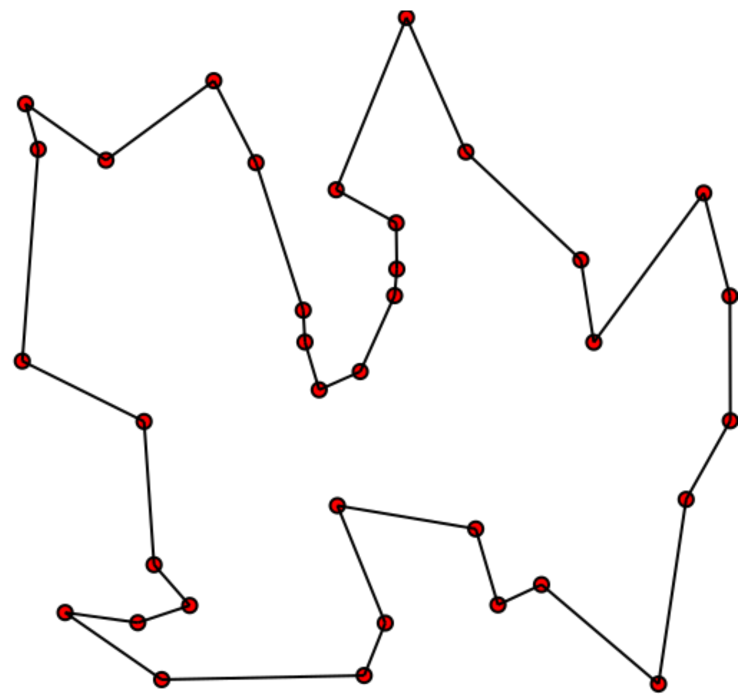
Broad Approach



Traveling Salesman Problem

Traveling Salesman Problem (TSP): *Given a collection of cities and the distances between each pair of cities, what is the shortest possible route for a salesman such that he/she visits all the cities and returns to the starting city?*

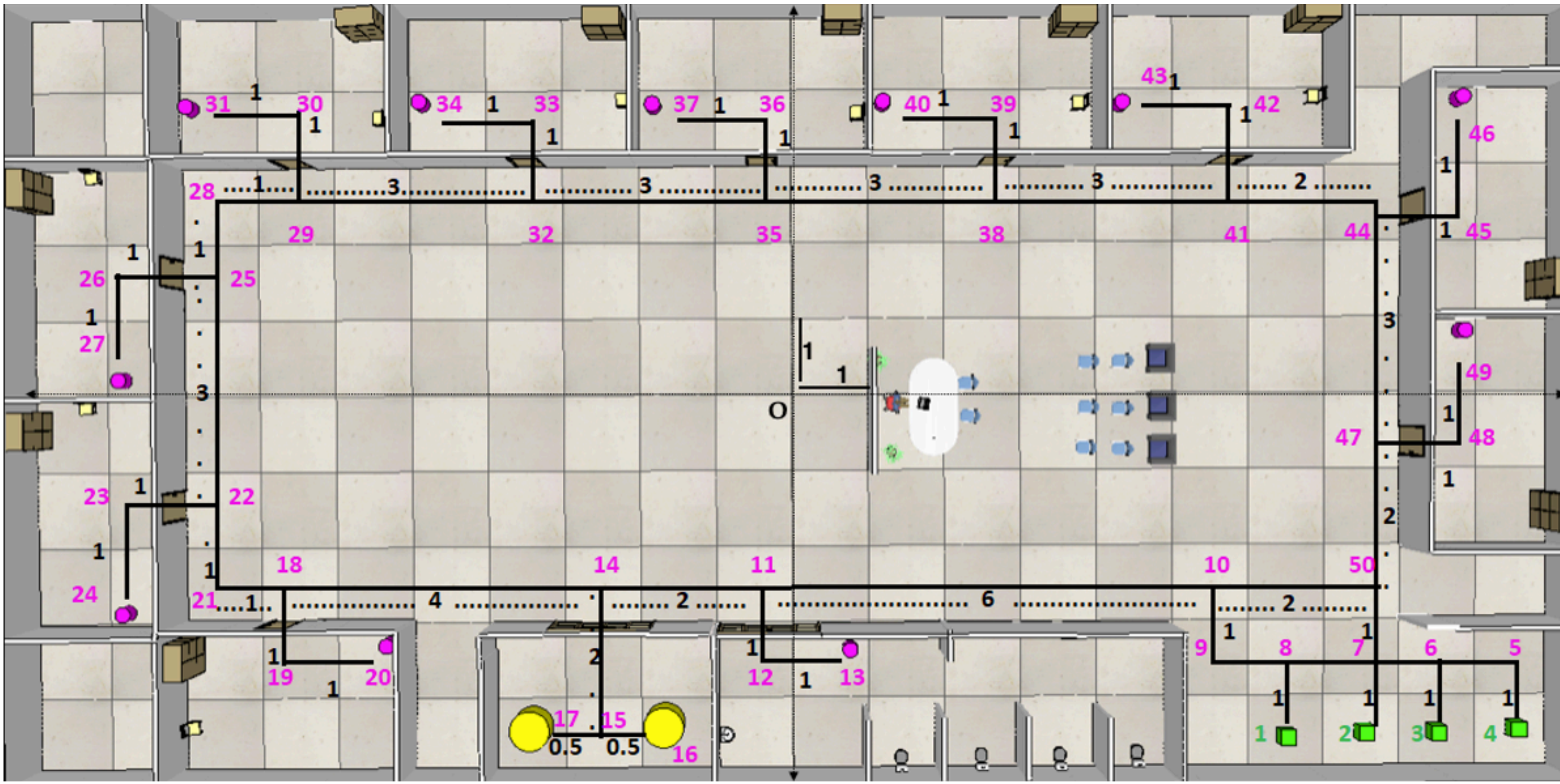
- Given a complete graph with weights on the edges, find the shortest path starting and ending at the same vertex which visits every vertex exactly once.
- It is an NP-complete problem.
- Can be reduced to solving an Mixed Integer Linear Programming (MILP) Problem



Traveling salesman plan

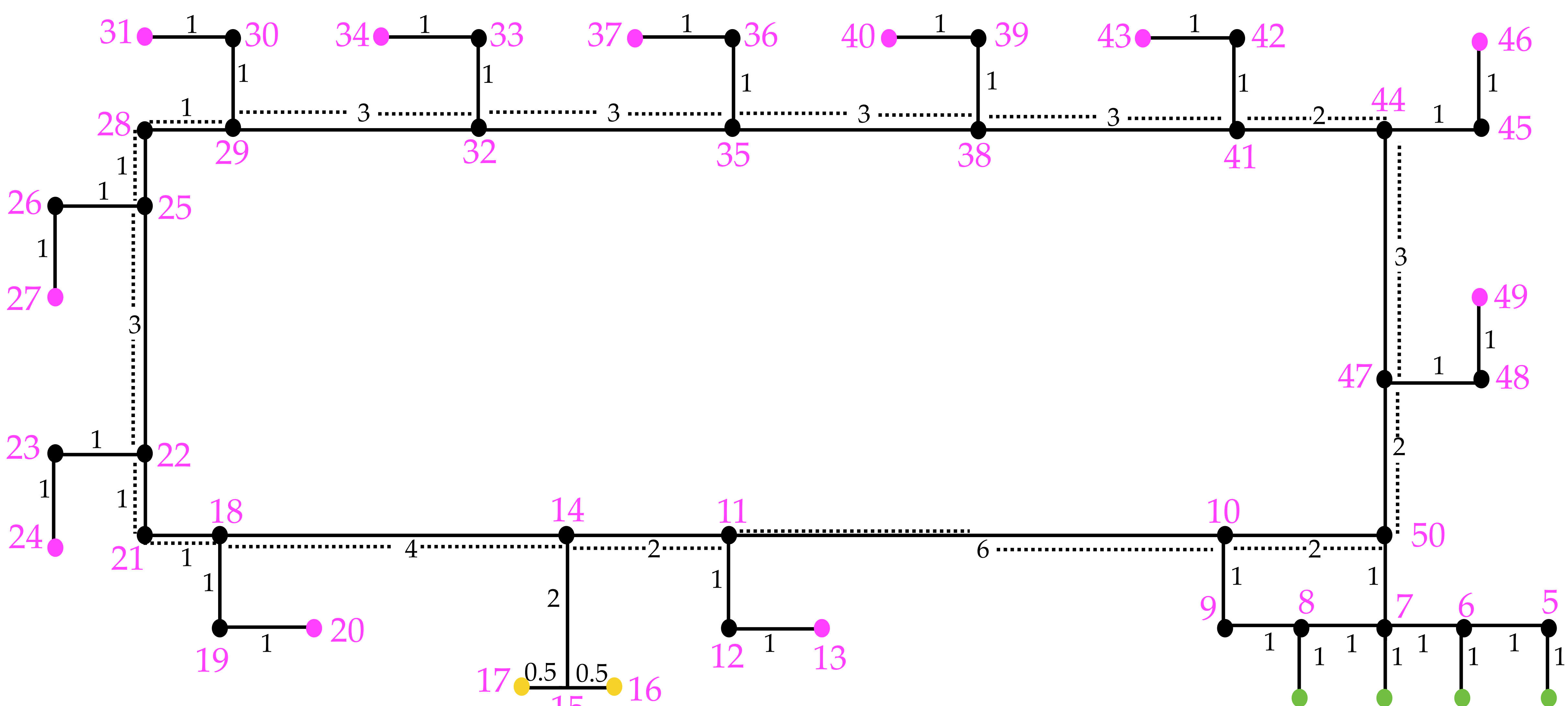
Multiple Traveling Salesman Problem (mTSP): *Given a collection of cities, the distances between each pair of cities and a depot where m salesmen are located, what are the routes for each salesmen such that the total route is shortest, and each city is visited exactly once by only one salesman?*

Environment



Hospital Environment

Weighted Graph

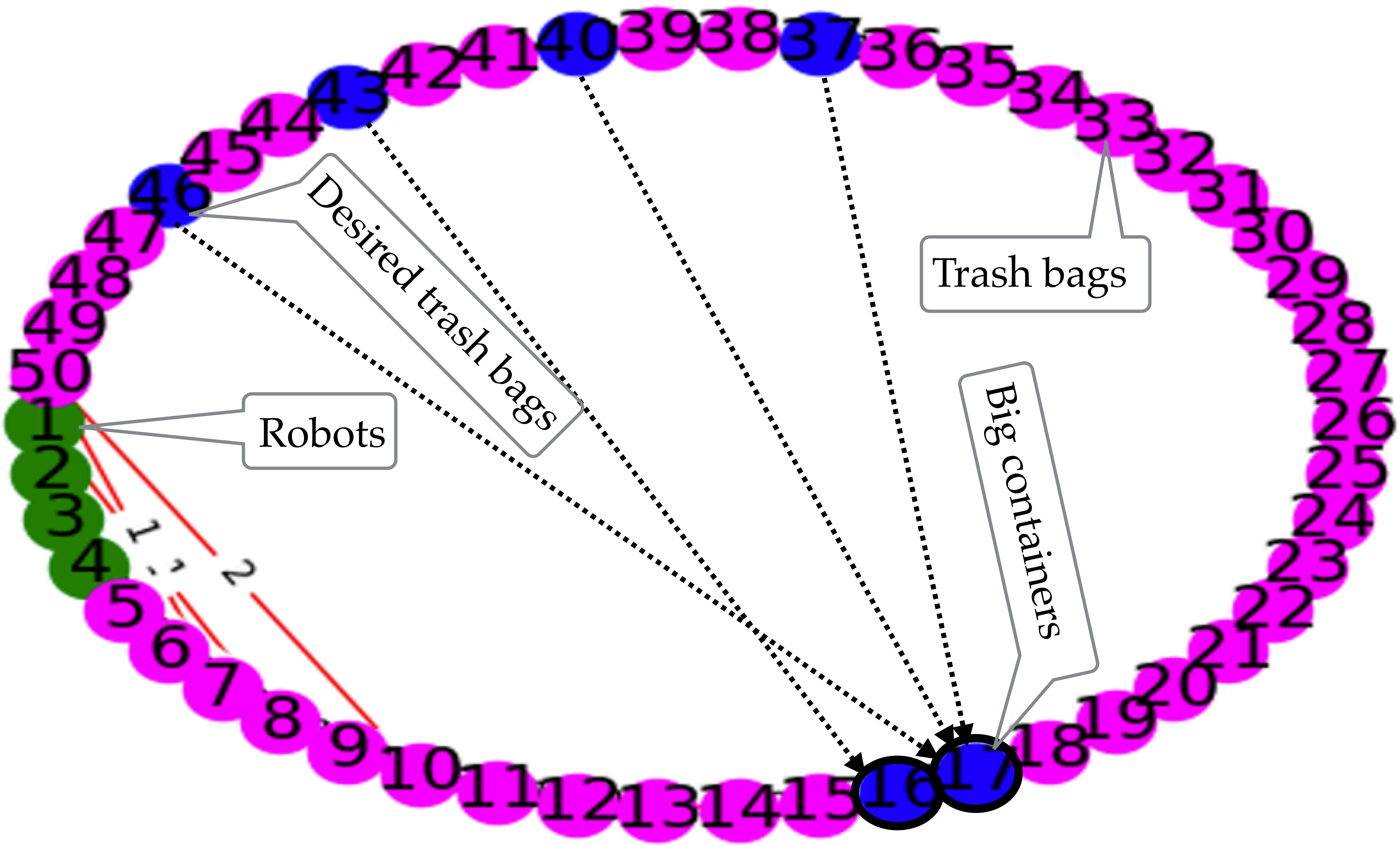


Weighted Graph

Weighted Graph: *consists of the following:*

- *Vertices are all the end points of line segments;*
- *Edges are all the line segments;*
- *Manhattan distance is considered for the length of an edge;*

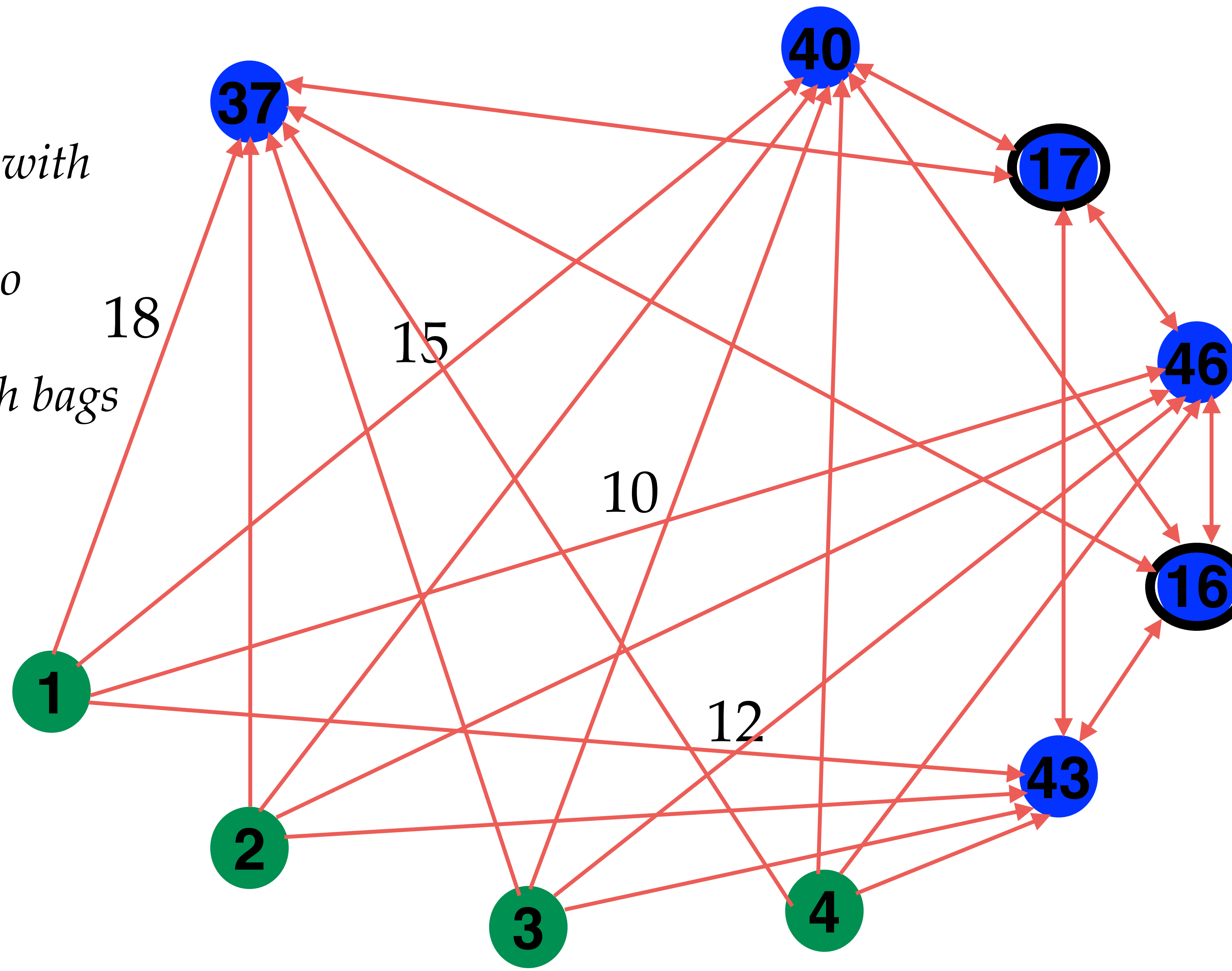
Weighted Graph



Weighted Graph

Task-based Weighted Graph

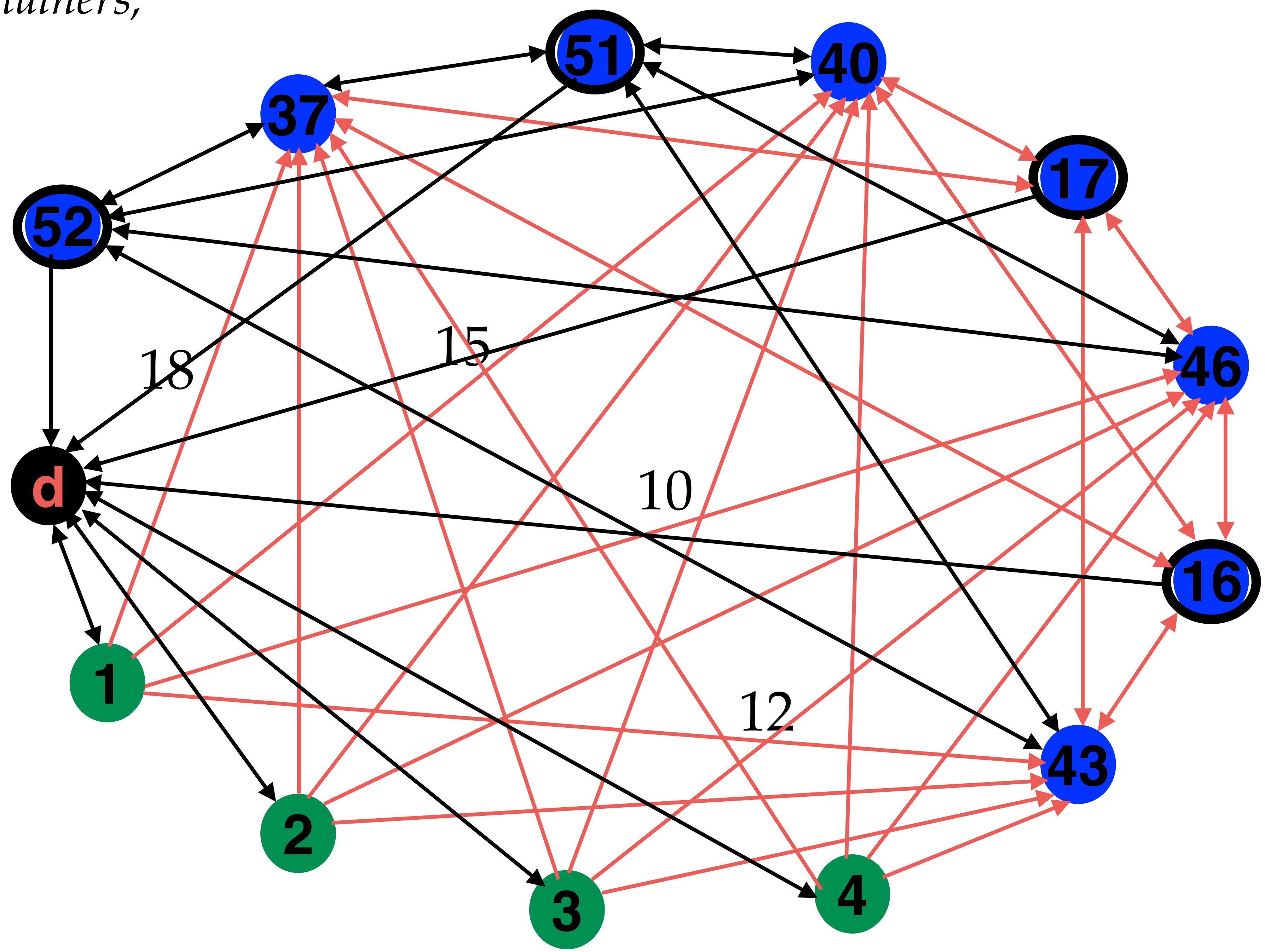
- *Create vertices for robots;*
- *Create vertices associated with the tasks;*
- *Create edges from robots to trash bags;*
- *Create edges between trash bags and big containers;*



Note: *Some big containers may need to be visited more than one.*

Task-based Weighted Graph for MTS

- *Create k-1 copies of a big container if k tasks share the same big container;*
- *Add all incoming and outgoing edges associated with the big container for all copied containers;*



Mixed Integer Linear Programming for mTSP

- Consider weighted graph G = (V, E, c).
- Vertex 1 denotes a common place.
- c(I, j) is the distance between i and j.
- x(i,j) denotes whether edge (i,j) is included in the plan.

Minimize $$\sum_{i,j \in E} c(i,j)x(i,j)$$

Constraints:

- Guarantee that exactly m robots depart from common place, that is,

$$\sum_{(1,j) \in E} x(1,j) = m$$

- Guarantee that exactly m robots return to the common place, that is,

$$\sum_{(j,1) \in E} x(j,1) = m$$

- Guarantee that exactly one sub plan visits each vertex, that is,

$$\sum_{(i,j) \in E} x(i,j) = 1, \ \forall \ j \in V/\{1\}$$

Mixed Integer Linear Programming for mTSP

- Guarantee that exactly one sub plan exits from each vertex, that is,

$$\sum_{(i,j)\in E} x(i,j) = 1,\ \forall\ i \in V/\{1\}$$

- Guarantee that there is no sub plan between vertices (Miller-Tucker-Zemlin),

$$u_i - u_j + n.x(i,j) \leq n-1,\ \forall\ 2 \leq i \neq j \leq n$$

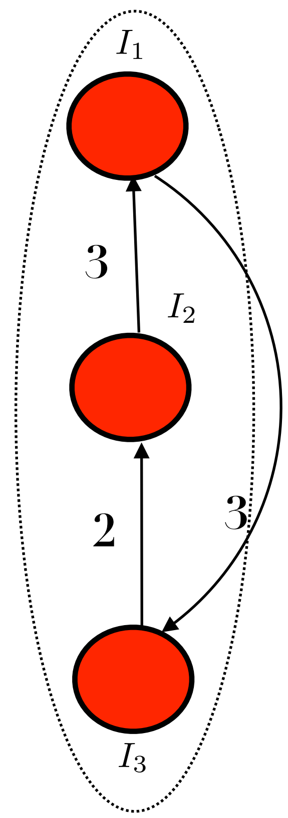
$u_i, u_j \in \mathbb{Z}$, n be the number of vertices.

$$u_{I_1} - u_{I_3} + n \leq n-1$$

$$u_{I_3} - u_{I_2} + n \leq n-1$$

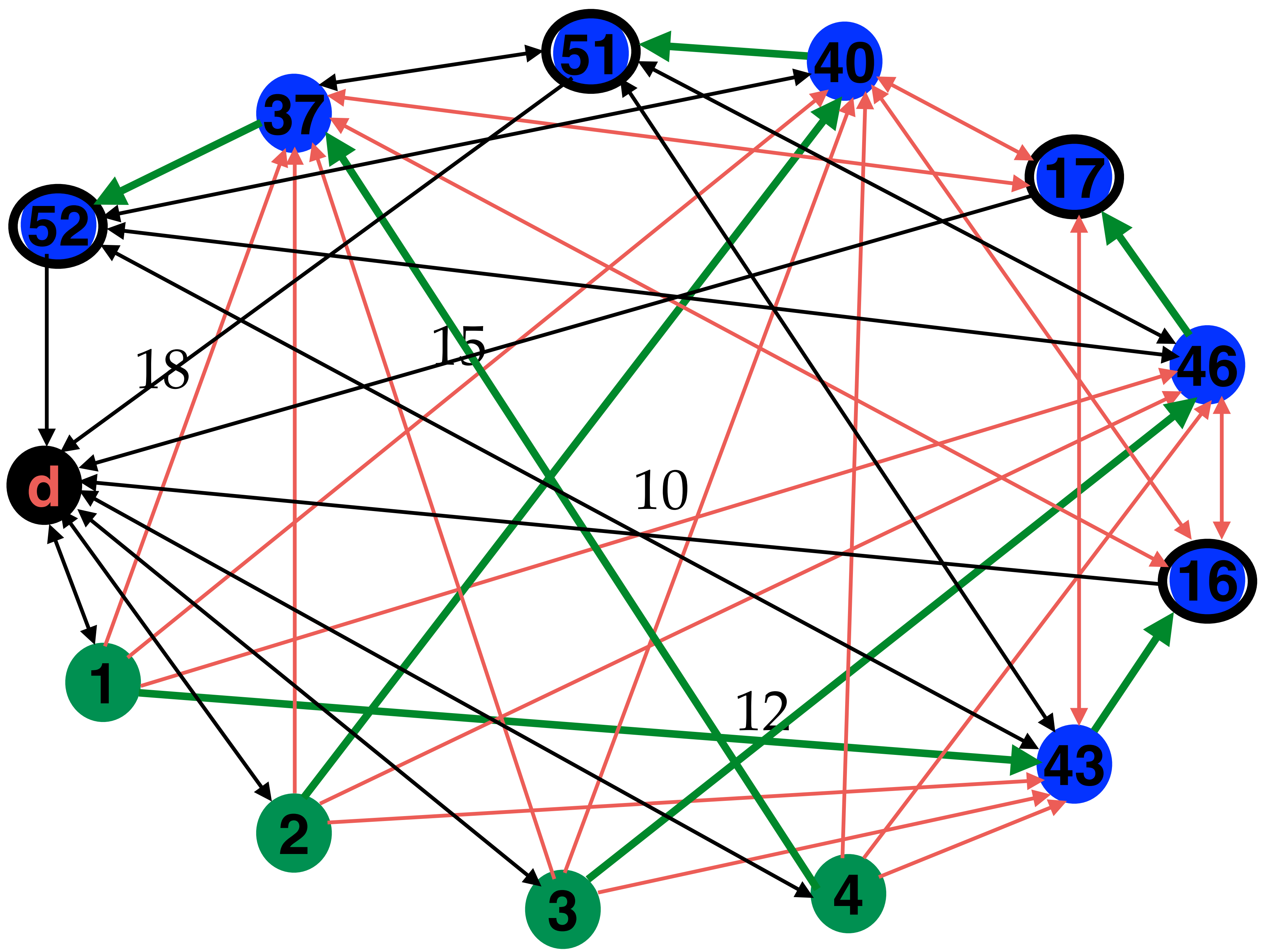
$$u_{I_2} - u_{I_1} + n \leq n-1$$

$$3n \leq 3n-3$$



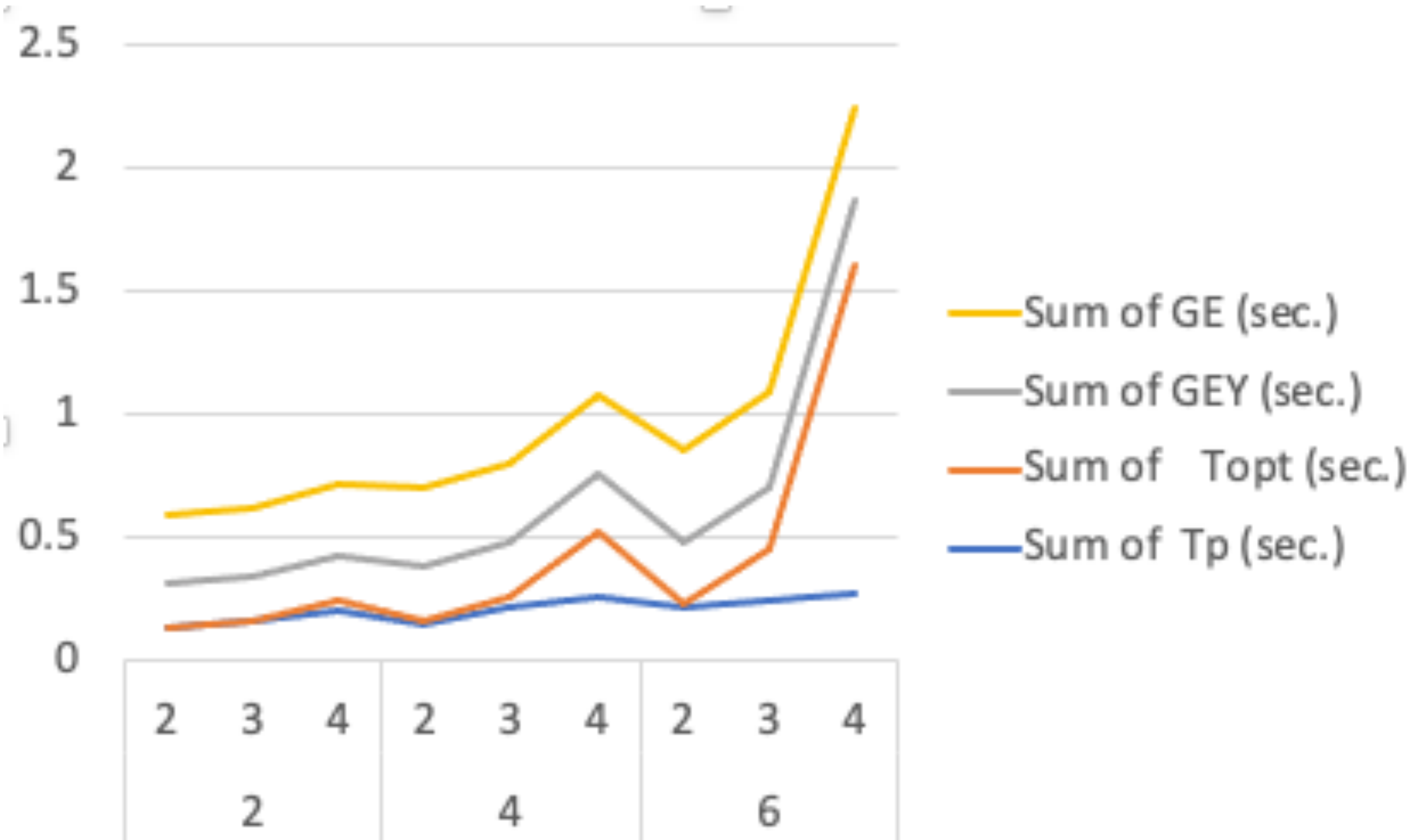
Sub-plan

Optimal Paths



Link: *https://drive.google.com/file/d/1__J3wNeJH_qnE0pTWYnmXXBsM4DpFac_/view?usp=sharing*

Experimental Analysis



Conclusion

Results:

- Presented optimal multi-robot path planning for the trash pick and drop problem
- Presented task-based graph approach
- Performed the experiments for different number of tasks in small, medium, and large hospital
- The experimental results show that the approach is scalable

Future Works:

- Extend our method for complex tasks
- Consider multi-objectives