Multi-Agent Autonomous Waste Collection System

FCUP

Introduction to Intelligent Autonomous Systems

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Introduction | Project Overview

In response to the challenges of **waste collection** in large urban areas, characterized by fluctuating levels of waste production and ever-changing road conditions, we have been tasked with developing an **efficient waste collection** ecosystem through a **Multi-Agent System (MAS)**. This system employs multiple autonomous agents — each operating independently but communicating through **decentralized protocols** — to dynamically distribute tasks and ensure optimal waste collection.


Agents

Agents | Overview

During the development of the project, we designed **3 main Agents**:

→ **Truck Agent** - Responsible for navigating the environment to **collect waste from bins** and deliver it to a central disposal facility.

→ **Bin Agent** - Functions as a waste storage unit that **accumulates trash over time**, simulating the variable waste production in urban areas.

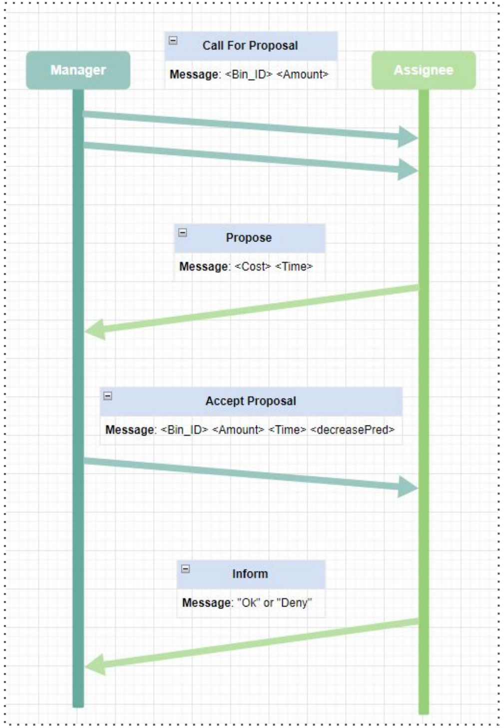
→ **God Agent** - Introduces random disruptive events, such as **simulated disasters or obstacles**, which impact the Truck Agent's decision-making.

Agents | Communication Protocol

To improve inter-agent communication for the **exchange of valuable information** — such as **cost values** for specific tasks and their efficient allocation to agents within the environment — we have developed an **adapted version** of the **Contract Net Protocol**.

This adaptation introduces a **promotion-demotion behavioral mechanism** based on task availability for current trucks without tasks to perform, enabling them to switch between **Manager and Assignee roles**.

Agents | Communication Protocol | Decision-Making



Initially, all trucks without assigned tasks are **promoted to managers**. These manager trucks then **initiate negotiations with the remaining trucks** — referred to as **assignees** — using various performatives to convey task-specific information.

They **request cost estimates** from each assignee for collecting trash from a selected bin which is assigned to the truck that provides the **best cost** - the one that **better trades-off between the distance and fuel costs** to perform the task.

Consequently, the assigned truck queues up all the given tasks and is ready to perform them.

Agents | Communication Protocol | Strategies

To more accurately represent societal waste production, our bin agents **generate variable amounts of trash** depending on the time of day which increases the variability of trash pickups by the trucks, reflecting **real-world fluctuations**.

Additionally, to simulate traffic conditions, we introduced a **time-of-day-dependent penalty** in the cost calculations for performing a trash pickup which accounts for factors like **increased congestion during peak hours**, affecting the overall efficiency and cost of waste collection.

Agents | Communication Protocol | Strategies

When a assignee gets **stuck** in a location whether it is due to **environmental causes** (**Roadblocks**) or to **internal failures** (**Mechanical Breakdowns**), they **redistribute all their uncompleted tasks to all the other assignees**, mimicking the Manager's behaviour.

In cases of a **roadblock**, the assignee **waits for conditions to normalize** before resuming any remaining tasks.

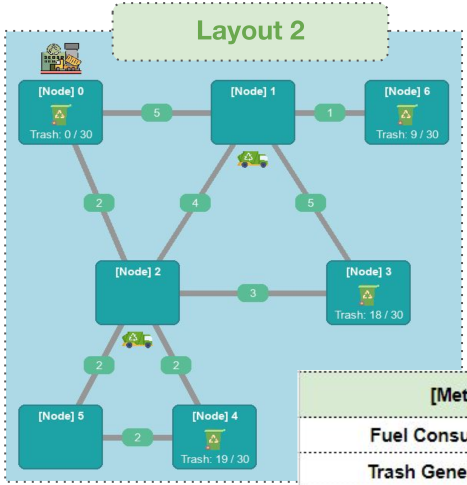
However, if **immobilization** is due to a mechanical breakdown, the assignee is marked as **inoperable and assumes the role of a bin**, allowing other assignees to retrieve and manage its uncollected trash.


Experimental Results

Experimental Results | Baseline

As an initial step to evaluate the **impact of our agents** on the graph, we conducted an 8-minute simulation representing a 24-hour period, focusing on **one of the three developed graph layouts** for assessment.

For our **baseline study**, we have defined the starting configuration to include a **number of bins and truck agents equal to half the total number of nodes in the graph**, with three agents per type.



[Metrics] Baseline	
Fuel Consumed	267
Trash Generated	386
Trash Collected	475
Trash Deposited	287
Trash Overspill	0
Avg Truck Distance Travelled	34.00
Avg Bin Collection Time	21.22

Experimental Results | Increased Number of Trucks

[Metrics] Increased N. Trucks	
Fuel Consumed	66
Trash Generated	386
Trash Collected	572
Trash Deposited	92
Trash Overspill	0
Avg Truck Distance Travelled	12.28
Avg Bin Collection Time	20.14

When comparing the results between the Base Case and the one with more trucks, we can make a few observations. The **Trash Collected** and **Average Bin Collection Time** remain roughly the same while the **Trash Overspill remains at 0** as there is no shortage of trucks.

However, with more trucks in operation, **each truck travels a shorter distance and collects less trash** overall. Consequently, the Overall Fuel Consumed, Trash Deposited at the Base, and Average Truck Distance Travelled are **significantly reduced**.

Experimental Results | Increased Number of Bins

On the other hand, the comparison between the Base Case and the one with an **increased number of bins** reveals that the **Average Bin Collection Time decreases**, while every other metric increases substantially.

This suggests that **increasing the number of bins** while maintaining the same number of trucks is inefficient. It **increases the workload for each truck**, leading to **higher fuel consumption and longer distances traveled** to collect and deposit additional trash. As a result, **overspill occurs** because the trucks cannot keep up with the bins' fill rate.

[Metrics] Increased N. Bins	
Fuel Consumed	321
Trash Generated	842
Trash Collected	856
Trash Deposited	724
Trash Overspill	11
Avg Truck Distance Travelled	46.8
Avg Bin Collection Time	24.98

Conclusions and Future Work

Our **decentralized approach** ensures independent behavior among truck agents working toward the **common goal of trash collection**. However, this can lead to suboptimal routing — trucks may **prioritize nearby tasks over global efficiency**, resulting in increased fuel consumption, longer completion times, overlapping paths, and inefficient travel distances.

To address these issues, we plan to **implement heuristics that consider overall fuel consumption** to further **optimize agents' decision-making** during task allocation. Additionally, we'll explore **dynamically adding or removing trucks** based on the **demand of bins** in the environment.