



UNIVERSITY OF LEUVEN (KUL)  
DEPARTEMENT OF COMPUTER SCIENCE

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**Multi-Agent Systems**  
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*By:*  
Karsten DAEMEN  
Michiel STAESSEN

*For:*  
prof. Tom HOLVOET  
dr. Robrecht HAESEVOETS

## 1 Introduction

This paper will outline a *Delegate Multi-Agents System (DMAS)* solution that uses *Ant Colony Optimalisation (ACO)* techniques to solve the dynamic *Pickup and Delivery Problem (PDP)*. The performance of this solution will be compared with two other classic *Multi Agent Systems (MAS)*, *ContractNet* and *Gradient Field*.

The considered PDP assumes that a truck can only transport one package at the time and that new packages can randomly be added to the system. The infrastructure will also remain the same and congestion on road segments will not occur.

All of the agents in the presented DMAS solution are simulated in a virtual environment (e.g. a private cloud). It is not very affordable or even practical to equip every pickup and delivery location (in the physical environment) with a communication device. These locations can change a lot and these devices are necessary because agents on these locations have to be able to communicate with each other. Because the whole DMAS is run on the virtual environment, truck drivers (in the physical environment) will only need some kind of GPS device to receive the planned path from the simulation in the virtual environment.

The purpose of this paper is only to outline the implementation of an ACO based DMAS for PDP. Therefore, the reader is supposed to have a decent knowledge of *Multi-Agent Systems (MAS)* and the applications of *Ant Colony Optimalisation (ACO)* techniques in *Delegate Multi-Agent Systems (DMAS)*.

## 2 Approach

The DMAS solution we developed defines two agents, *Package Agents* and *Truck Agents*. All Package Agents have a corresponding package and are located on their pickup location. Truck Agents have a corresponding truck and move along with the truck. Both agents also own a *pheromon table*. These tables can hold multiple paths (list of Package Agents in a certain order) and a corresponding pheromon (heuristic value).

Package Agents and Truck Agents communicate with each other by sending ants. These are a sort of smart messages.

There is also a "*forwarder*" placed in each delivery location of a package. These "*forwarders*" will send all received ants to the Package Agent corresponding with the package for the local delivery location. Because of their limited intelligence, forwarders are not considered to be agents.

Like most DMAS based on ACO, three type of ants will be used, they will be used in the following way:

- **Feasability Ants**, these ants will be periodically broadcasted over a certain radius from the Package Agents to the forwarders. Their main purpose is to inform other Package Agents which Package Agents are in a certain radius near their delivery location.
- **Exploration Ants**, these ants will be sent from the Truck Agents to discover and evaluate a path of Package Agents. They will update the pheromons table in the Package Agents during their return over the discovered path.
- **Intention Ants**, these ants will be sent from the Truck Agents over the path of Package Agents that they are planning to do. These ants will decrease the pheromon values for that path in the visited Package Agents.

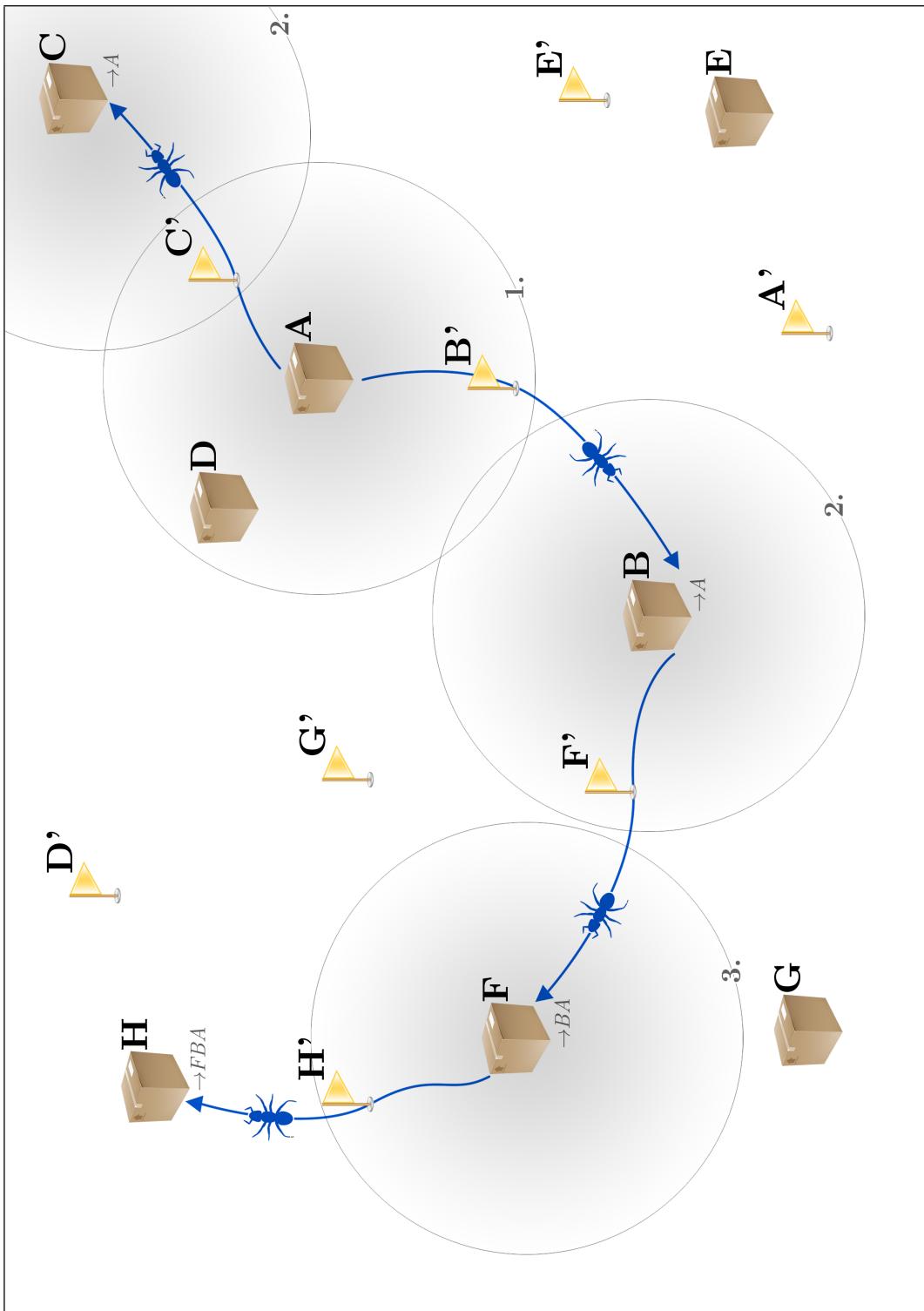
How agents find an optimal path by using the pheromones and communication over ants is further explained by the following scenarios.

### Scenario I: Broadcasting of Feasibility Ants

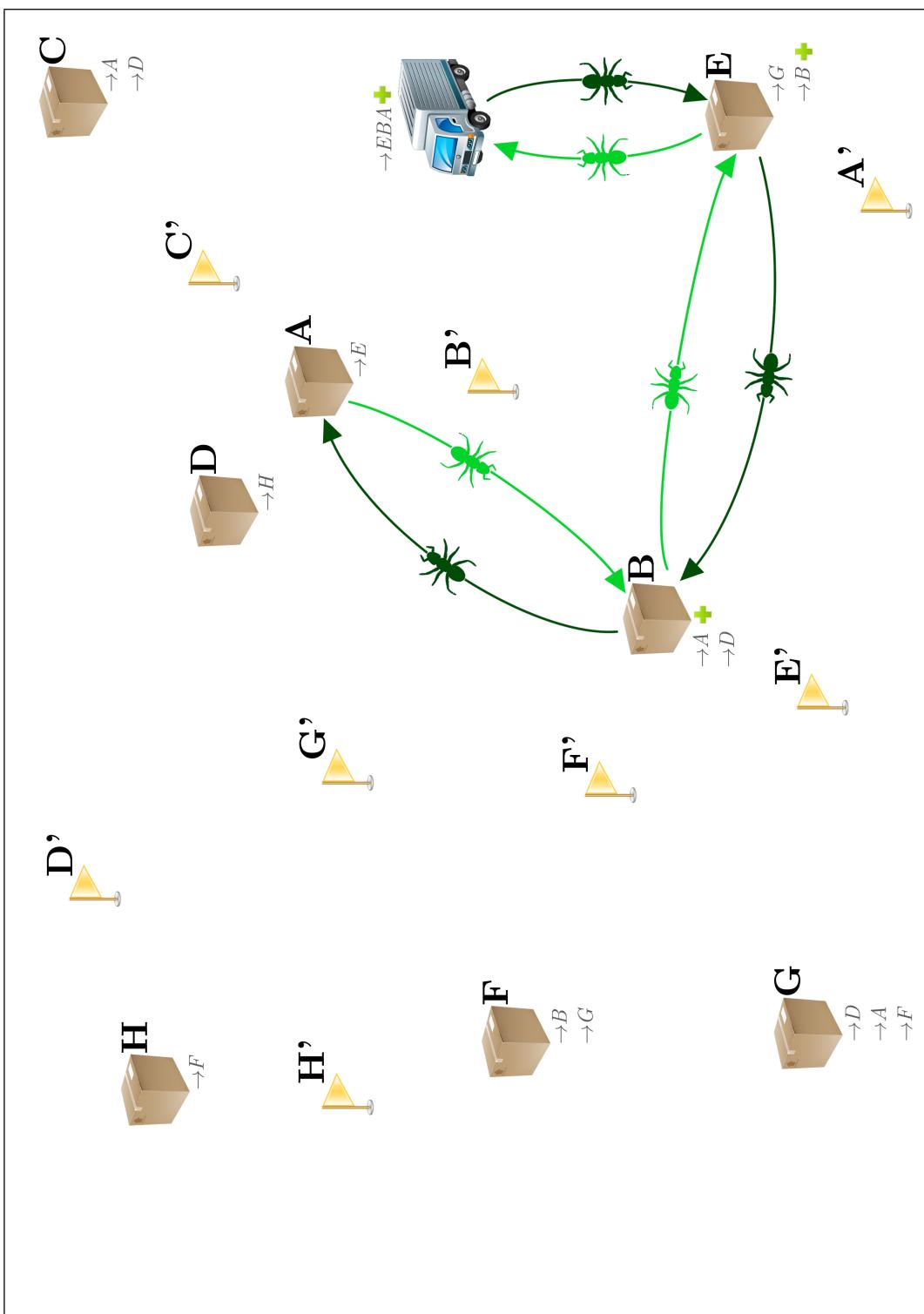
When Package Agent A (depicted as a brown box 'A' in Figure 1) is added to the simulation it will broadcast a Feasibility Ant with origin "A" in a certain radius to all forwarders (depicted as a yellow flags in Figure 1). Forwarders C' and B' receive the feasibility ant and send it to their corresponding Package Agents C and B. These Package Agents now know that after they are delivered the package A is near. After C and B have added path "A" to their tables with a default pheromon value, they will change the origin of the Feasibility Ant to "CA" and "BA" respectively and broadcast it again. This time, on

This process goes on until the max number of hops (= number of times broadcasts

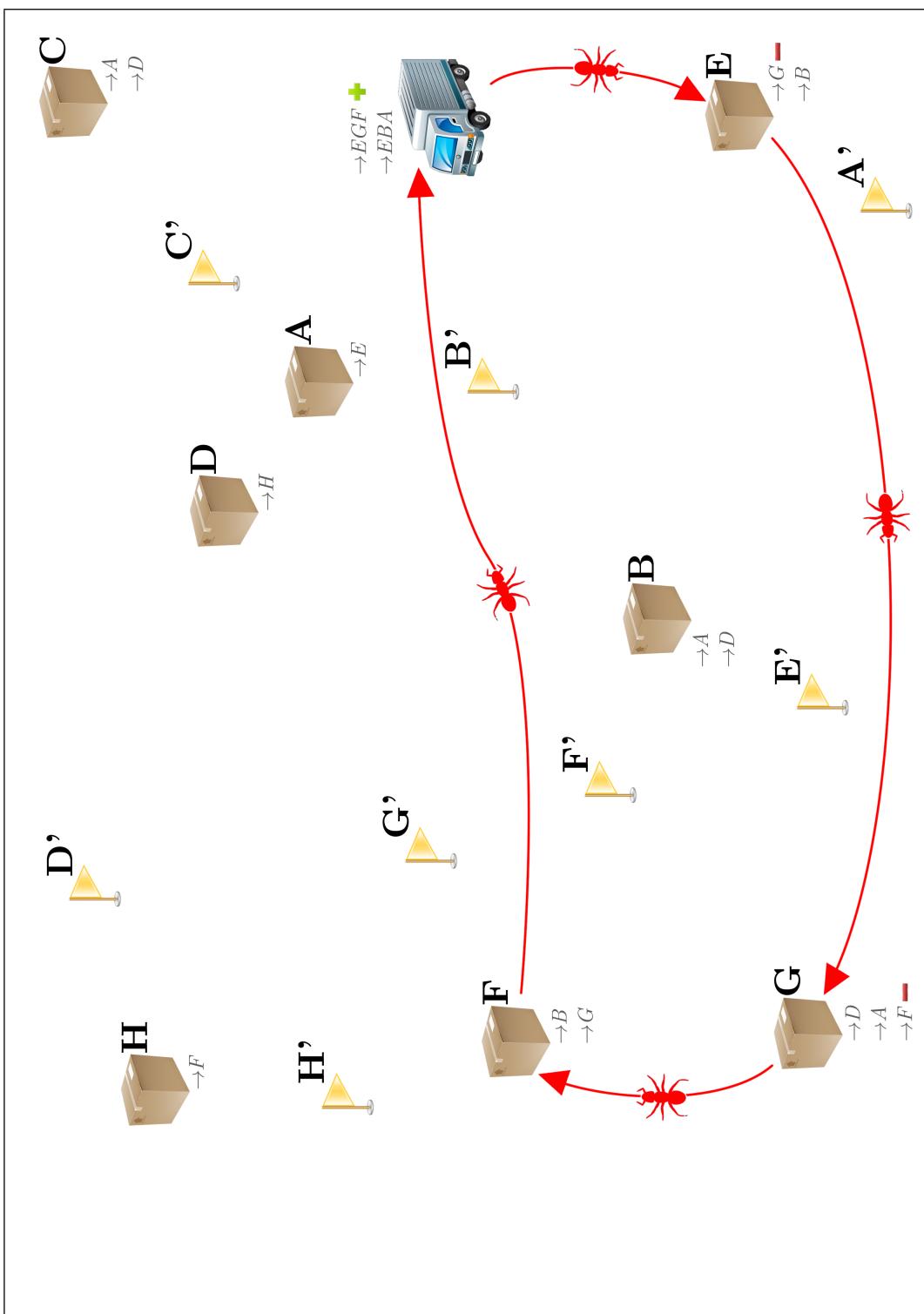
The max number of hops for Feasibility ants is in our application 1, i.e. only



Figuur 1: Example Scenario I (2)

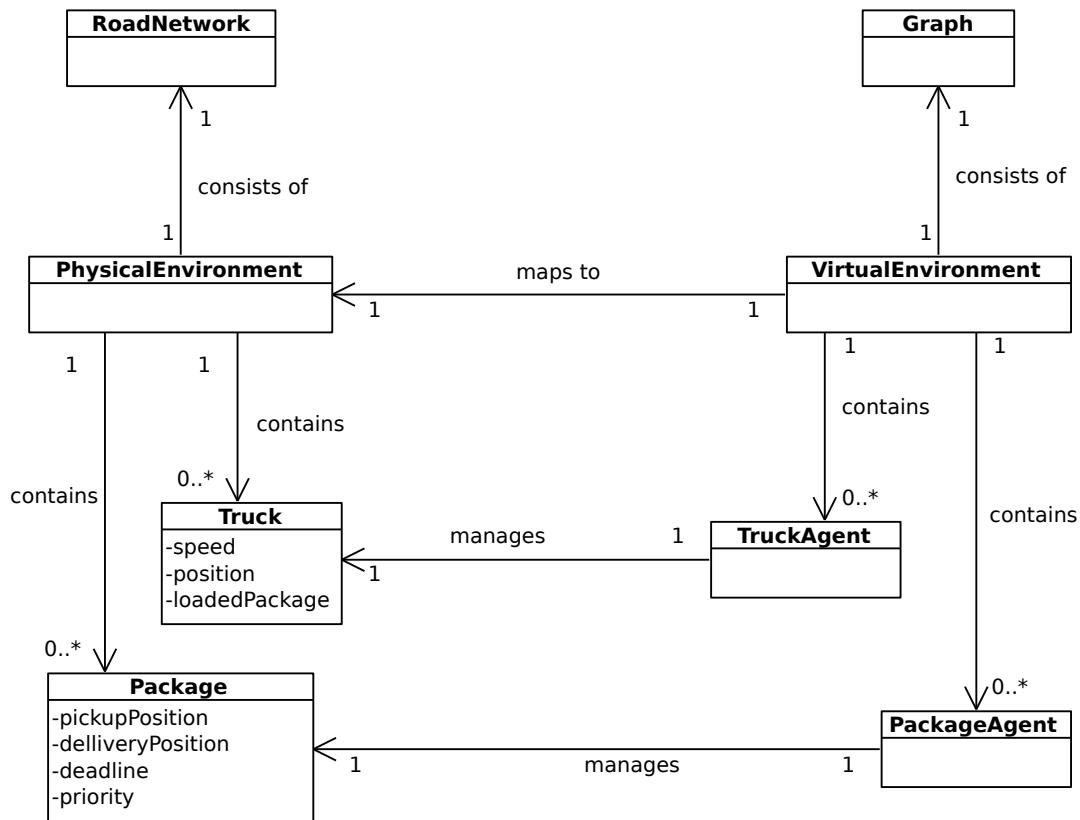


Figuur 2: Exploration Ants (example scenario 2)

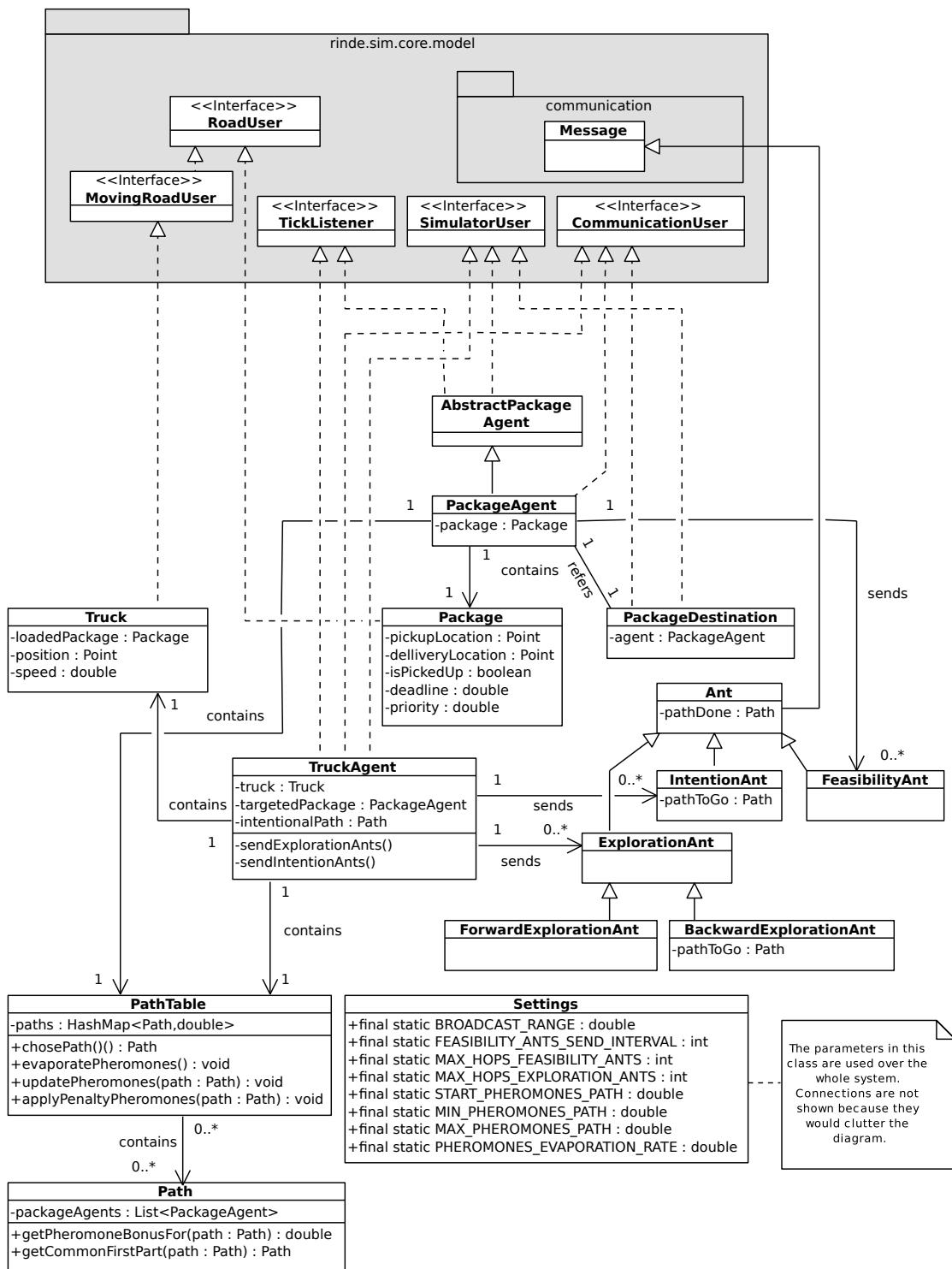


Figuur 3: Intention Ants (example scenario 3)

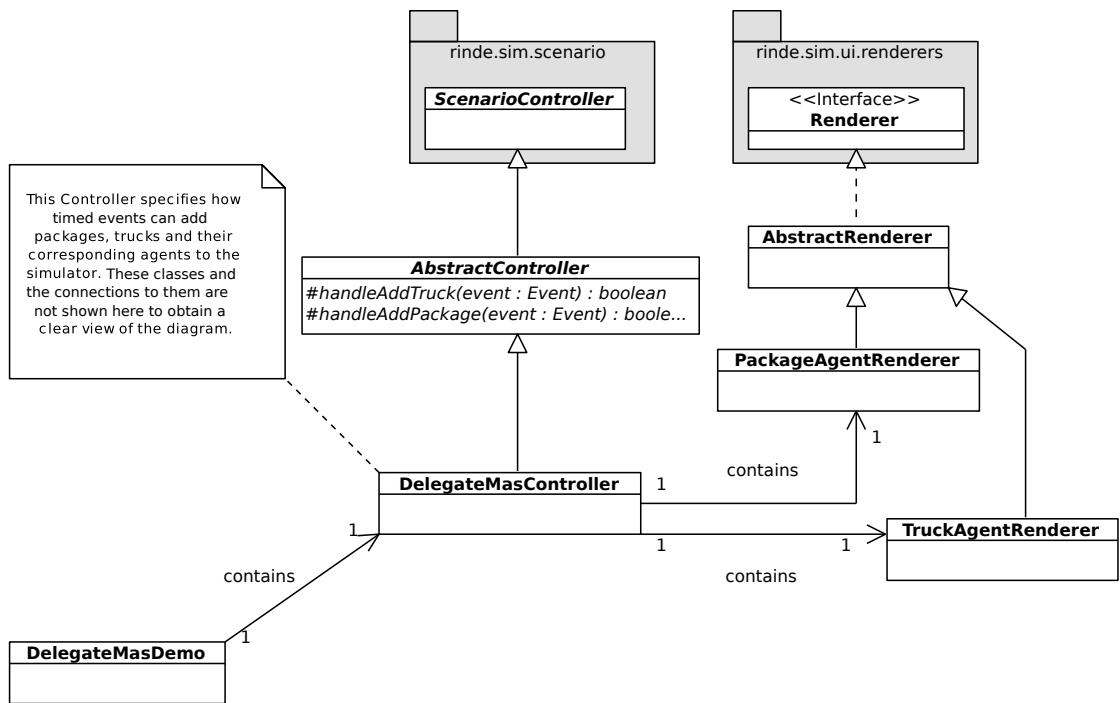
### 3 Development



Figuur 4: Class Diagram (part I)



Figuur 5: Class Diagram (part I)



Figuur 6: Class Diagram (part II)

## 4 Evaluation

In order to evaluate the DMAS solution, it is compared to two reference solutions: Gradient Field and Contract Net. We will describe them in a nutshell.

Gradient Fields are based on electrical fields: packages and trucks have opposite charges and will thus attract each other. However, trucks will repel other trucks because they are able to move and have equal charges. This will make sure that the work is divided among all trucks.

In a Contract Net, package agents will broadcast the position of their packages. (Some) Truck agents will receive the broadcasted message and respond with an offer to pick up the package. The package agent will then evaluate all the offers it received and inform the senders whether they won the offer or not. When a truck receives an accepted proposal, it can still decide that there is a better alternative. In this case, the package agent is informed of a failure. The contract is now broken and the package will again broadcast the position of its package.

### 4.1 Experiments

As explained in ??, the DMAS solution will try to plan an optimal route. As a consequence, we are particularly interested in the performance of this system. We test this in a number of ways.

First, the overall performance is measured by counting the number of delivered packages in a fixed time window.

Second, we track the time that passes between the creation of a package and the pickup. This can serve as an indication for the responsiveness to dynamism.

Third, all packages should be delivered within a given time window. Therefore, the lateness for every delivery is logged.

Finally, to evaluate the efficiency of the chosen routes, the total distance travelled by trucks is also measured.

All this information is gathered during a fixed-time scenario in which a number of trucks start with an initial amount of packages. Every time a package is delivered, a new one is added. This will prevent the trucks from running out of packages and will not flood the system with too much packages either.

Because of the optimal path planning, we expect to see a high throughput (delivered packages) and a low value for total distance travelled.

### 4.2 Comparison

### 4.3 Critical Reflection

First of all, the system manages to get the task done. A huge advantage to this system is that it can plan ahead, whereas the Contract Net and the Gradient Field solution in particular

do not/cannot plan ahead. Using heuristics, the delegate MAS solution can find an optimal path throughout the system.

One of the disadvantages about this system is that it will not always find packages at a given moment. Sometimes, it is required to navigate randomly until packages nearby can “hear” the truck agent. One way to solve this problem would be to periodically increase the broadcast radius of truck agents (up to a maximal range) when no packages are found in a certain time window.

Another way to solve this problem could be to combine multiple solutions into one hybrid solution. When no packages are found, a Gradient Field could be used to spread the agents across the physical environment. This will increase the coverage of the map and hence the chance for packages to be heard by trucks.

## **5 Conclusion**