University of Bordeaux 1
Science and Technology
Computer Science specialty

Second year of Master - Study and Research Project

Mobility Models for UAV Group Reconnaissance Applications

MEMORY

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Thanks

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The help of our clients, misters Serge CHAUMETTE and Vincent AUTEFAGE, was also very precious for us. The proposed article was really very interesting. The main subject of this study concerns a matter seen during this half-year. We thank them to have provided an interesting article.

We also wish to thank mister Arnaud CASTEIGTS, who provided us with a lot of help to understand the JBotsim library, and to go over the difficulties we met with the implementation on JBotsim.

To finish, we thank the English professors, Messrs Jean-Christophe COQUILHAT and Jean-Jacques BERNAULTE. They helped us to correct this report and to improve it in linguistic terms.

Introduction

As part of our Master's degree in Computer science at the New University of Bordeaux particularly in the Study and Research Project, we had to study a research article in groups of 5 people. Every group had to choose a subject of research among those proposed. Our group chose a topic related to the drones. The title of this article is *Mobility Models for UAV Group Reconnaissance Applications* written in collaboration by *Erik Kuiper* and *Simin Nadjm-Tehrani* published in 2006. The customers who suggested us studying this article are Messrs Serge Chaumette and Vincent Autefage. Our teaching assistant is mister Pascal Desbarats.

This project, for a period of 3 months, we were able to see the progress of the study of a research article, its reading in English, with the implementation of an algorithm, and going through a study of the existing. The aim of this matter is to make us study a research article, to extract an algorithm from it and to implement it. We must therefore study a model that meets the aerodynamic properties of drones.

Many mobility models exist and are often based on the real world. This article specifically discusses two mobility models that are Random Mobility Model and distributed Pheromone Model.

We tried to give the best possible image of our project through this memory. It represents each stage, from the study of the existing to the implementation of an algorithm. It also shows our organization as well as the multiple tests which we established and carried out.

Chapter 1

Context

A drone is an unmanned aircraft remote-controlled or autonomous. It is equipped with different sensors (accelerometer, gyroscope, magnetometer, camera, etc..) And they allow it to move in its environment.

Today, UAVs are increasingly present on the French territory and around the world. There are different types of drones with different missions. For example, some drones are monitoring (building, historical monuments ...), others are designed to collect information, others have military uses or transport.Two types of UAVs are currently present: the so-called civilian drones and military drones. In the military context, UAVs can be used to penetrate areas that may be too dangerous for humans. They may include mapping areas for the tracking area.

Much research has been dedicated to these devices for many years, including several drones cooperating and communicating together. These fleets of drone were used to perform tasks as efficiently as possible. We need to know how they move together, deal with collision avoidance, avoid to do twice the same work etc ... These constraints can be resolved through mobility models based on communication.
Many research topics are dedicated to these types of mobility within fleets drones. They study the different ways of drones' moving in their environment all together.

The purpose of this article is to scan an area previously defined as soon as possible and if possible once per hour. The problem of this article is: **How to scan an area well? As much as Quickly as possible in a limited time and at least, once every hour**.

Chapter 2

Analysis Of Existing models

As said before, drone swarms are governed by these models mobility. Our study of existing models is therefore divided into several parts.

2.1 Summary of the problem

The issue of this paper is to scan an area as efficiently as possible and as quickly as possible, at least once per hour. This area will be scanned by a UAV swarm that will cooperate and communicate together.

2.2 Existing models

Many mobility models exist with different characteristics. All these models are used to define movements for swarm of UAV. Most models are based on real-life situations such as road maps, or on the behavior of many animals (ants, birds, termites, wolves etc). We will expose some of them we consider the most important and most interesting for our case.

2.2.1 Random Walk

First described by Einstein in 1926, it was developed to mimic the extremely unpredictable movement of many entities in nature. A mobility node (MN) moves from its position to a new one by randomly choosing a direction and speed chosen by pre-defined ranges, [speedmin, speedmax] and [0, 2PI]. At the end of a constant time interval t or a constant distance traveled d, a new speed and direction are calculated. If a MN during its travel reaches a simulation boundary, it « bounces » off the simulation border with an angle determined by the incoming direction and continues to this new path.
It's a memory-less mobility pattern because it retains no knowledge of its old locations and speed values. Therefore, the current position and speed of a MN is independent from its past location and speed. This can generate unrealistic movement because of sudden stops and sharp turns. If the specified time or distance of a MN motion is short, the resulting movement pattern will be a random roaming pattern restricted to a small part of the simulation area. Figure 2.1 shows an example of the movement observed from this model. All the MN begin in the center of the 300mx600m simulation area (at the position (150,300)). Every 60 seconds, each MN randomly chooses a direction between 0 and 2PI, and a speed between 0 and 10m/s.

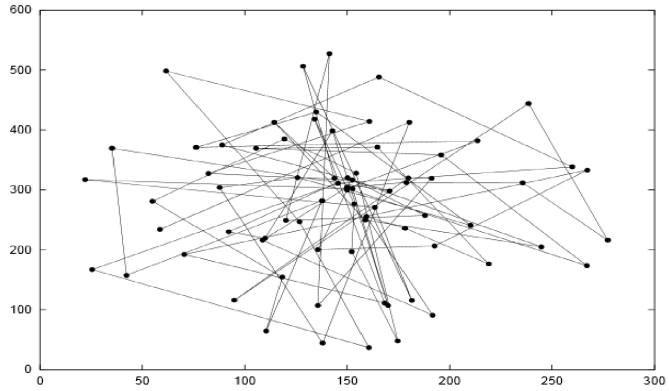


Figure 2.1: Resulting pattern of a MN using the Random Walk Mobility Model

2.2.2 Random Waypoint

It includes pause between changes in direction and/or speed. Once this pause expires, the MN chooses a random destination and a speed, that is uniformly distributed [minspeed, maxspeed]. The movement pattern of a MN which uses the RWaypointMM is similar to the RWalkMM if pause time is zero and [minspeed, maxspeed] = [speedmin, speedmax]. Figure 2.2 shows an example of the resulting pattern from the Random Waypoint Mobility Model.

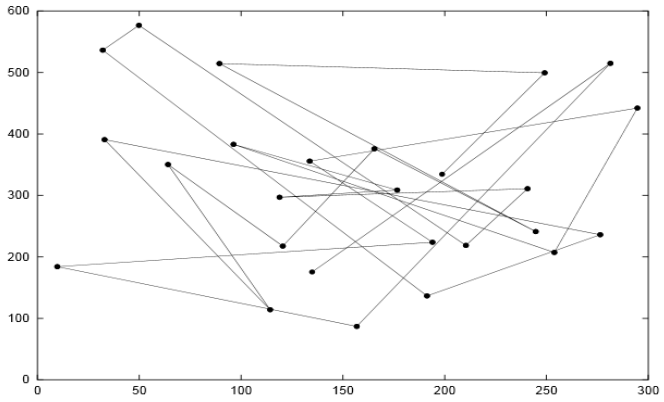


Figure 2.2: Resulting pattern of a MN using the Random Waypoint Mobility Model

During a run, MNs are initially distributed randomly around the simulation area. Figure 2.3 shows the average MN neighbors percentage of the MNs. The average is the cumulative percentage of total MNs that are a given MN's neighbor. Therefore, if the network has 20 nodes and a node has 2 neighbors, then the node's current neighbors percentage is 10%. Moreover, during the first 600 seconds, due to initially distributed randomness of the MNs around the simulation area, there is an high variability in the average MN neighbors percentage.
In the paper, three possible solutions are presented to avoid this initialization problem. The first is to save the location of the MNs after the initial high variability and use this position as the initial starting point of the MNs in the next simulations. The second is to change the initial distribution of the MNs in a specific area to be a distribution more common the model, like for example, initially placing the MNs in a triangle distribution. Lastly, the beginning of each simulation produces initialization problems due to the random distribution of the MNs around the simulation area. Throwing out the initial 1000 seconds of simulation time in each simulation ensures that the initialization problem is removed even if the MNs moves slowly. But if the MNs moves fast, we can discard fewer seconds of simulation time. This third solution ensures that each simulation has a random initial configuration.

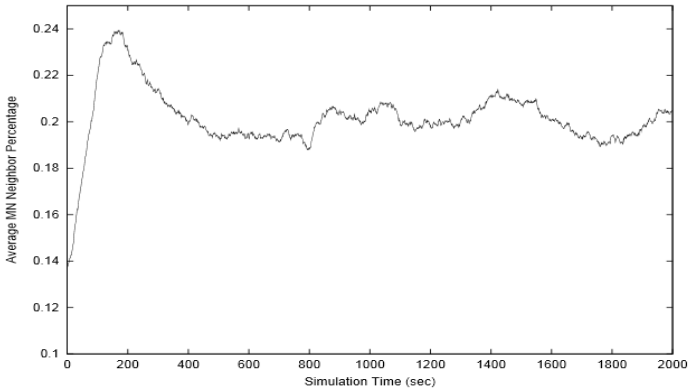


Figure 2.3: Average neighbor percentage vs. time

Random Direction

The Random Waypoint Mobility Model produces a clustering of nodes near the center of the simulation area (see the figure 2.2). To overcome this problem, the Random Direction Mobility Model was created to ensure an almost constant number of nodes throughout the area simulation.
In this model, a Mobility Nodes (MNs) chooses a random destination and it will travel to this in order to reach the border of the simulation area. When a MN reaches a simulation boundary, it pauses for a time specified by the simulation. Then it chooses an other angular direction between 0 and 180 degrees and continues to travel.
Figure 2.4 shows us the resulting path of an MN using this mobility model. This MN begins at the center of the area(150,300). The dots in this figure illustrate the moment when a MN reached a border, paused and chose a new direction to travel along.

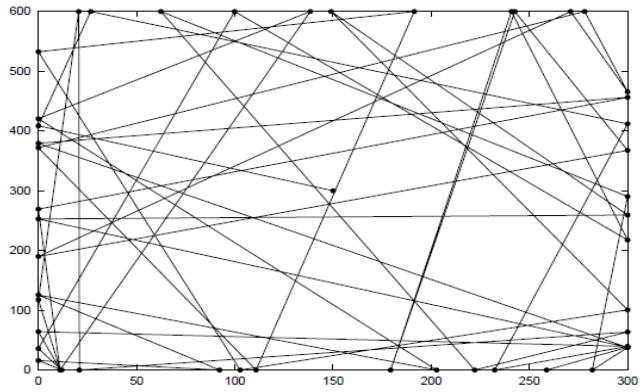


Figure 2.4: Resulting pattern of a MN using the Random Direction Mobility Model

A Boundless Simulation Area

In this model, there is an important relationship between the old direction and velocity and the current direction and velocity. A velocity vector V = (v,theta with v a speed and theta an angular) is used to describe an MN's velocity and a position of an MN is represented as (x,y). The velocity vector and the position are updated in a regular time t.
The Boundless Simulation Area Mobility Model is very different from other Mobility Models because here, an MN that reached a border of the simulation area continues its travel and reappears on the opposite side of the simulation area. It results from this that we can consider the simulation area like a torus-shape, illustrated by figure 2.5. The simulation area is transformed in two steps. Firstly, the top border is connected to the bottom border to create a cylinder and then we connected both open circular ends.

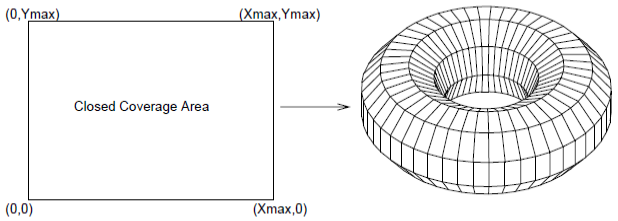


Figure 2.5: Area mapped to a torus

With a speed between 0 and 10 m/s, an angular between 0 and 90 degrees and a time t to 0.1 seconds, the results of the boundless mobility models with this parameters can be seen on figure 2.6

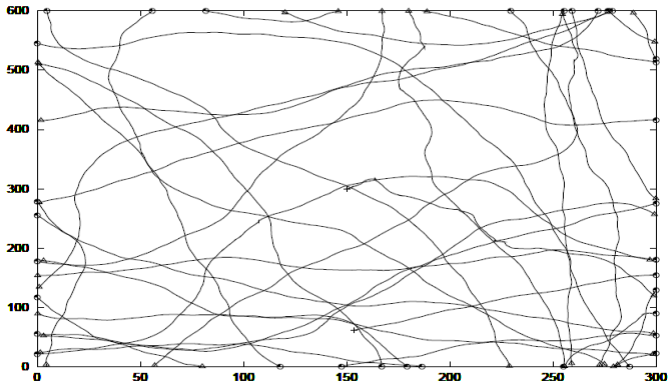


Figure 2.6: Resulting pattern of a MN using the Boundless Simulation Area Mobility Model

2.2.3 City section

The aim of this model is to propose a realistic model. It is based on the vehicle's movement on road maps. The specificity of this model is the map which depends on each geographical zone. Here, vehicles are mobile nodes.

The mapping data blocks are available from the Americans office of census. The map information is retrieved from text files. These files are composed of several elements:

- The unique identifier for a specified road.
- The nature of the road: it can be a highway or a street.
- The longitude of the start of position.
- The latitude of the start of departure
- The latitude of arrived.
- The longitude of arrived.

All the intersections of the map are represented by nodes not mobile. This model also considers the volume of traffic : the more there is traffic, the thicker the line representing the road. This model is also sensitive at the speed of cars (depending in particular on the hour). For example, we can consider that the speed of vehicular traffic in the morning is much smaller than at the beginning of the afternoon.

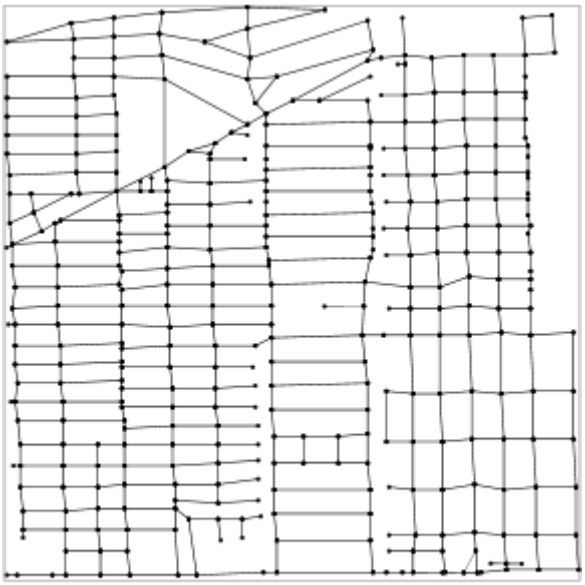
Here is the progress of this model. Every node begins in a point chosen randomly and its destination is chosen also randomly. The strategy of every node is to look for the shortest up to the destination. To achieve it, the Dijsktra algorithm is used. Several parameters have to be considered in this algorithm as the speed or the traffic. This route can be dynamically changed. When a node reaches its destination, it begins again all the process described previously. Concerning the node's speed, it is limited to more or less 5% of the speed registered in the file.

For example, here is a representation of the model. We see here that the traffic is a little sparse, but with very different speeds. The comparisons of these two regions base themselves on the inaccessible pairs, the length of the average route and to finish the changes of neighbors.

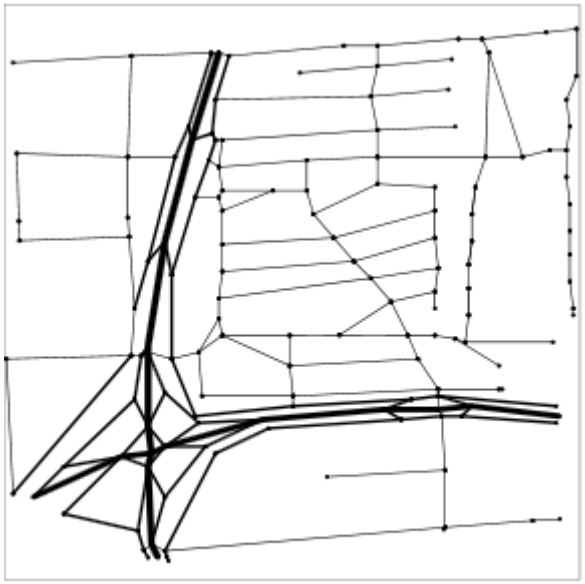
This article proposes two situations. The first situation, which they call region A, proposes a very dense road network with a constant speed limit on all the road network. The second situation, which they call region B, proposes a road network much less dense than the precedent, but with different speeds of movements.

The comparisons of these two regions base themselves on the inaccessible pairs, the length of the average route and to finish the changes of neighbors.

Here are representations of these two regions:



(a) Region *A*: Street scenario corresponding to a square area of size 2400 m×2400 m



(b) Region *B*: Street scenario corresponding to a square area of size 1900 m×1900 m

Région A

- Transmission range : 250 meters.
- 200 nodes.
- 10% of the pairs of nodes are unable to communicate.
- the connectivity of a network is poor
- New parameters : Transmission range : 500 meters.
- 50 nodes.
- Result : the connectivity fluctuates a lot.

Region B

- Transmission range : 250 meters.
- 200 nodes.
- 5% of the pairs of nodes were disconnected.
- Result: The connectivity is better than in the region A.
- New parameters : Transmission range : 500 meters.
- 50 nodes.
- The area covered in Region B is less than the area covered in Region A.
- The connectivity corresponding to Region B is better as compared to scenarios corresponding to Region A.

Another experiment was conducted on the two regions previously mentioned with a routing protocol called DSR. The DSR protocol consists of two mechanisms : Route Discovery and Route Maintenance. According to the article,

> To perform a Route Discovery for a destination node D, a source node S broadcasts a ROUTE REQUEST that gets flooded through the network in a controlled manager. This request is answered by a ROUTE REPLY from either D or some other node that knows a route to D. To reduce frequency and propagation of ROUTE REQUESTs each node aggressively caches source routes that the node learns or overhears.
> Route Maintenance detects when some link over which a data packet is being transmitted breaks[1].

Simulations were made by using 150 nodes with a wireless transmission range of 500m. The communication pattern consisted of 10 constant bit rate flows, each sending 4 64 Bytes data packets from the source to the destination. The evaluation of this protocol is made on 3 properties.

- Packet Delivery Ratio
- Packet delivery latency
- Packet overhead

Here are the results obtained with the DSR protocol:

Table 2: DSR performance with 150 nodes and wireless transmission range of 500 m (averages)

Mobility Model	Packet Delivery Ratio	Delivery Latency	Packet Overhead
Our model	0.905	0.0182 s	141862.6
Random Waypoint	0.916	0.0142 s	115795.6

Figure 2.7: DSR Performance

We see that the obtained results are very similar in the Waypoint model. The average path length does not differ much.
We can conclude that from it the Waypoint model is a very good approximation of the model concerning streets.
Numerous improvements are possible so that the model is realistic :

- Changing settings depending on the time (lots of car in the morning for example).
- Possibility of introducing obstacles.
- Currently, each vehicle moves independently. But in real life, it has to pay attention to its environment.
- The model does not take into account the waiting time in the intersections.

To conclude, this model uses real life data. A called DSR protocol was used to test the model. We were able to notice that the Waypoint model is a good approximation of the model concerning streets.

2.2.4 Gauss-Markov

The aim of this model is to be able to adapt with one parameter to different levels of randomness.
Each MN has a current speed and direction. The speed and direction of each MN are updating at a regular time t. At each time t, the next destination and speed are calculated based on the current position of the MN. The MNs are forced away from an edge when the location of a MN is near a border of the simulation area, by modifying the angular direction of the MN as illustrated in figure 2.8.

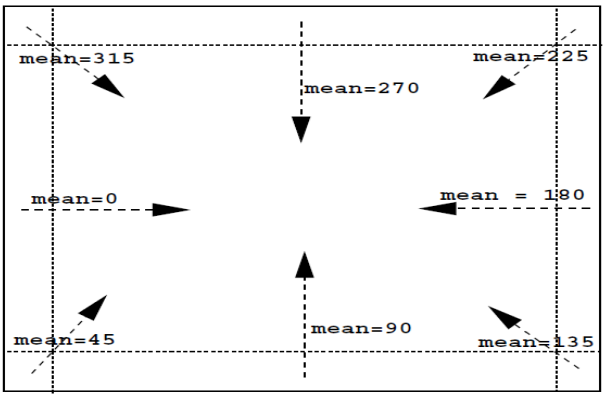


Figure 2.8: Change of angular direction near a border

In figure 2.9, an example of a resulting pattern of a MN using the Gauss-Markov Mobility Model is illustrated. The run takes 1000 seconds and the MN beings at the center of the simulation area. The parameter t is 1 second, the initial angular is 90 degrees and the speed is between 0 and 10 m/s. The Gauss-Markov MM can eliminate the sudden stops and sharp turns encountered in the Random Walk Mobility Model by saved past velocities and directions in order to be able to influence future velocities and directions.

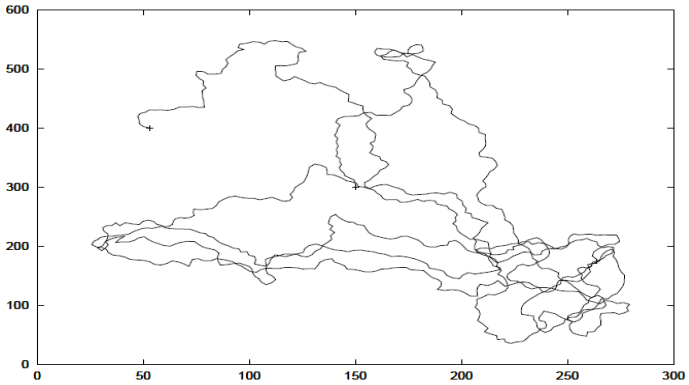


Figure 2.9: Traveling pattern of an MN using the Gauss-Markov Mobility Model

2.2.5 Reference Point Group Mobility Model

Group movements are based on the movement at the center of the group. The movement of the group center completely characterizes the motion of the MNs of its group, including their direction and speed. Each MN randomly and individually moves about their own pre-defined reference points, where their movements depend on the group movement. Their position are regularly updated each time t and a new direction is calculated for every MN according to the center of the group.
The figure 2.10 shows us an illustration of a group of three MNs that move together. The Random Waypoint Mobility Model is used for the random motion of each individual MN in the group and the movement at the center of the group.
In the paper, an application of this model is explained. The RPGMM can be used for example in an avalanche rescue scenario. In a scenario like this, the cooperation between human and canine is essential. We can see the human as the center of the group and the dogs are the MNs of the group.

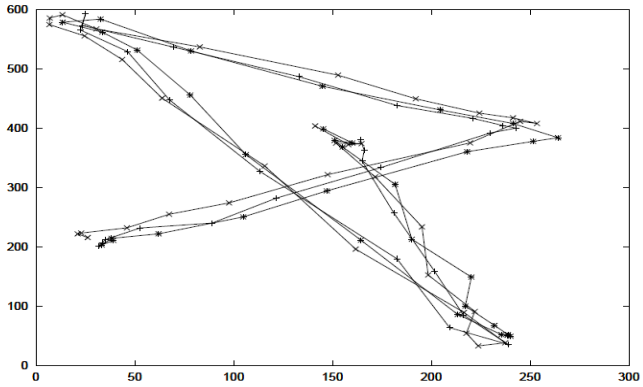


Figure 2.10: Resulting pattern of a MN using the Boundless Simulation Area Mobility Model

2.2.6 Social Network Theory

This model is based on the theory of social networks and on the decisions and the social behavior of human beings. For example, how human beings move in a group, and between groups. A notion of relation between the people is thus identified.
In this model, the individuals and the groups of individuals are considered as entities of the first one classes. The second class represents the strength of the social links (probability of collocation).

Representation of social networks is made through weighted graphs, by defining the weights associated with each edge of the network to model the strength of direct interactions between individuals. The degree of interaction is a value between 0 and 1. 0 represents no interactions, 1 represents a strong interaction. The model assumes a level of interaction less than 0.25 represents a social interaction disconnection.

$$\mathbf{M} = \begin{bmatrix} 1 & 0.75 & 0.60 & 0.91 & 0.11 & 0.05 & 0.00 & 0.03 & 0.20 \\ 0.75 & 1 & 0.23 & 0.81 & 0.24 & 0.03 & 0.13 & 0.18 & 0.21 \\ 0.60 & 0.23 & 1 & 0.30 & 0.28 & 0.03 & 0.01 & 0.02 & 0.17 \\ 0.91 & 0.81 & 0.30 & 1 & 0.65 & 0.13 & 0.14 & 0.23 & 0.04 \\ 0.11 & 0.24 & 0.28 & 0.65 & 1 & 0.23 & 0.13 & 0.11 & 0.05 \\ 0.05 & 0.03 & 0.03 & 0.13 & 0.23 & 1 & 0.83 & 0.44 & 0.55 \\ 0.00 & 0.13 & 0.01 & 0.14 & 0.13 & 0.83 & 1 & 0.71 & 0.03 \\ 0.03 & 0.18 & 0.02 & 0.23 & 0.11 & 0.44 & 0.71 & 1 & 0.94 \\ 0.20 & 0.21 & 0.17 & 0.04 & 0.05 & 0.55 & 0.03 & 0.94 & 1 \end{bmatrix}$$

Figure 2.11: Matrix of interactions between nodes

The objective of this model is to use social relationships between the individuals to define groups of hosts who move together along with the scenarios. The first step is the generation of the social network. It is represented by a matrix of interaction 18.

People can be grouped according to their social links or compared with their geographical location. Dynamic mechanisms are present in this model. The people can belong to a group at moment T, and change group afterward. The notion of distance is taken into in account in the parameters.
An incalculable number of scenarios can be set up. Every group moves with a random speed and every host has a random speed of its own. A host, belonging to a group, moves inside this one. He can reach for example an aim which was fixed to its. Nodes not belonging to any group move randomly.

When a node reached its aim, it has to make a choice: either it stays in the group to which it is up, or it chooses to be alone. This choice is made according to the rate of sociability of the group.The node will join the group which exercises most attraction.

Two scenarios are presented for this model. They are characterized by a number of different nodes and a different number of groups. The zone of simulation is a square of 1km

on 1km, the zone of a group is of 200m. Every group has a speed between 1 and 2 m/s and every node has a speed between 1 and 3 m/s. The first scenario includes 30 computers (representing nodes) consisted in 5 geographically different groups. The second scenario includes 60 computers distributed in 5 groups. In both cases, 80% of nodes are in a group. Thanks to these scenarios, we can obtain the average degree of connectivity of this model.

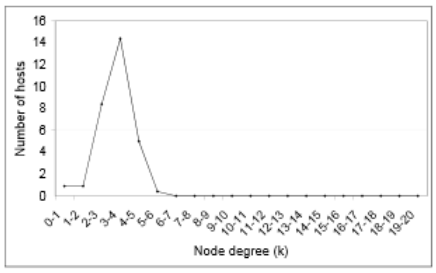


Figure 1: Distribution of degree of connectivity (scenario with 30 hosts grouped into 5 groups).

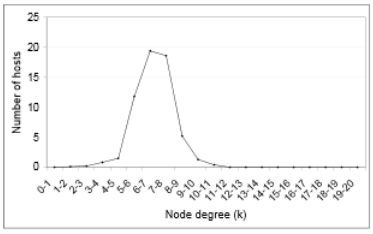


Figure 2: Distribution of degree of connectivity (scenario with 60 hosts grouped into 5 groups).

In conclusion, as regards this model, we can say that generally, the models of existing mobility leans on random movements which are very simplistic and most of the time unrealistic. It is necessary to make models which base themselves on real elements. Here, it is human socialization which is put forward. But this model can still be improved for example by adding obstacles.

2.2.7 Pheromone

Description of the model

This model is inspired by real pheromone. A pheromone is a chemical substance, secreted externally by certain animals, such as insects, affecting the behaviour or physiology of other animals of the same species.[1]
This model use digital Pheromone.This pheromone has 3 properties :

- Deposited and withdrawn pheromone from an area. (Information fusion and aggregation).
- Evaporated over time. (Forget old information = Truth maintenance).
- Propagated from a place to its neighboring places. (Information diffusion and dissemination).

A digital pheromone represents information about the system. Different "flavors" of pheromones convey different kinds of information.
We can have for example, attractive pheromone or repellent pheromone. The attractive pheromone will attract other UAVs whereas the repellent pheromone will repulse other UAVs. Digital pheromones exist within in an artificial space called a pheromone map.

[1] `http://dictionary.reference.com/browse/pheromone?s=t`

Scenario possible

Pheromone logic can be used for several types of surveillance and target acquisition and tracking scenarios.

- Surveillance and Patrol

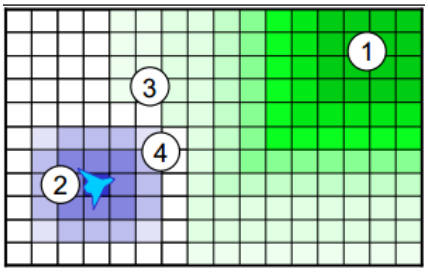


Figure 2.12: Attractive and repulsive pheromones for surveillance

In Figure 2.12, each step mean :
1. Surveillance area deposits attractive pheromone,
2. UAV deposits repulsive pheromone,
3. Pheromone infrastructure propagates both attractive and repulsive pheromone to form gradient,
4. UAV climbs net gradient, withdrawing attractive pheromone.

- Target Acquisition

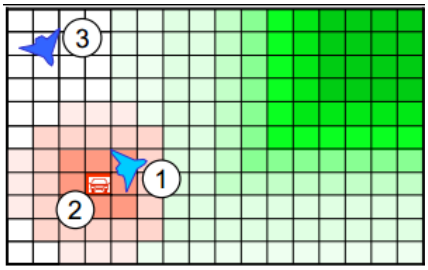


Figure 2.13: Pheromones attracting confirming sensors

In Figure 2.13, each step mean :
1. UAVdet detects target and Red target is created,
2. Red target deposits “NeedsID” pheromone,
3. UAVid is more attracted to NeedsID pheromone than lawn pheromone and climbs gradient to ID target.

- Target Tracking

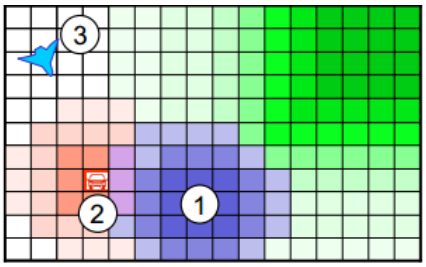


Figure 2.14: Pheromone tracking algorithm

In Figure 2.14, each step mean :
1. UAV acquires target and large Visited pheromone deposit repelling other UAVs,
2. Red target estimates movement, deposits “Tracking” pheromone that eventually overcomes strength of Visited pheromone,
3. Nearby UAV is more attracted to Tracking pheromone than repelled by Visited pheromone and climbs gradient to reacquire the target.

Real scenario

We are going to see a real scenario which demonstrate the use of pheromone model.
The demonstration used:

- Four robots
- A mock urban area
- Two UAVs controlled by pheromone technology

The demonstration focused on the swarming algorithms that control and coordinate the behaviors of the heterogeneous mix of vehicles.
Pheromone algorithms controlled and coordinated the flight of the two UAVs as they performed continuous surveillance over an urban area looking for potential adversaries. The two air units worked together to ensure even, thorough, and continuous coverage of all areas in the surveillance region while avoiding any collisions. They also provided patrol coverage of a mock convoy as it moved through the area.
While the UAVs surveyed a broad area over the airfield, the ground robots surveyed and patrolled around some mock buildings set up for the demo.
During the demonstration, one of the ground robots failed. The other ground robots were able to dynamically readjust their patrol patterns to accommodate the missing unit without any intervention by the operator.
This unplanned event helped to demonstrate the robustness of these algorithms to unexpected events. The demonstration showed cooperative behavior between the air and ground units when the identity of a potential adversary detected by one of the UAV's was automatically confirmed by one of the ground robots with a special sensor capable of target identification.
The operator simply gives a high level command to the whole swarm, such as "survey this area and track any identified targets" or "patrol around this convoy".
The robots autonomously configured themselves to determine which robot would perform what task in order to accomplish the overall objective.

2.2.8 Natural Agent

The basic idea of this article is the simulation of mobile model by basing itself on animal behavior. Animals, called a mobile agent in the article, cannot be separated from the environment in which they are and through which they interact. This idea is often ignored in the works on computer multi-agent systems, or the researchers consider the environment as a communication framework liability.
A multi-agent system is a three-tuple :

- a set of agents, Each agent, which is a four-tuple constitued of :
  - a set of agent,
  - a state,
  - an input
  - and an output(subset of state)
- an environment.
- and a process which allows to change the state of the agent.

The presence of input and output shows that the agents are limited processes : Environment, and a coupling.
The environment is a 2-tuple which is a subset of an agent.
It has a state and a process.
The environment is active. It has its own process which can change its state. The works on the artificial agents lean on the artificial intelligence. None agents only can predict the effect of its actions on the environment, because they do not depend on an agent but of a set of agent.
Thereafter, we are going to describe you the different mobile agents described in this article.

Ants

The ants model is based on the fact that ants build networks of paths. These paths link their food source available to their nest. Each ant who eat has the same program:

- It must avoid obstacles.
- If there is no pheromone on the map, it can go where it wants (random trajectory).
- If it finds some food, it depose pheromone during a time t. These pheromones indicate to other ants the location of the food.
- If an ant finds some food, it pick them up if it's not holding any and brings back the food to its nest.

Ants can die. Either they don't find food enough rapidly, or predators kill them.
All pheromone paths link to food. But the pheromones evaporate over time. The rate of pheromone can be reinforced if many ants come through the same path.
Here is a representation of the behavior of ants (This diagram is from `http://pro.cleamax.fr/info-bioinspiree/?p=fourmis`) :

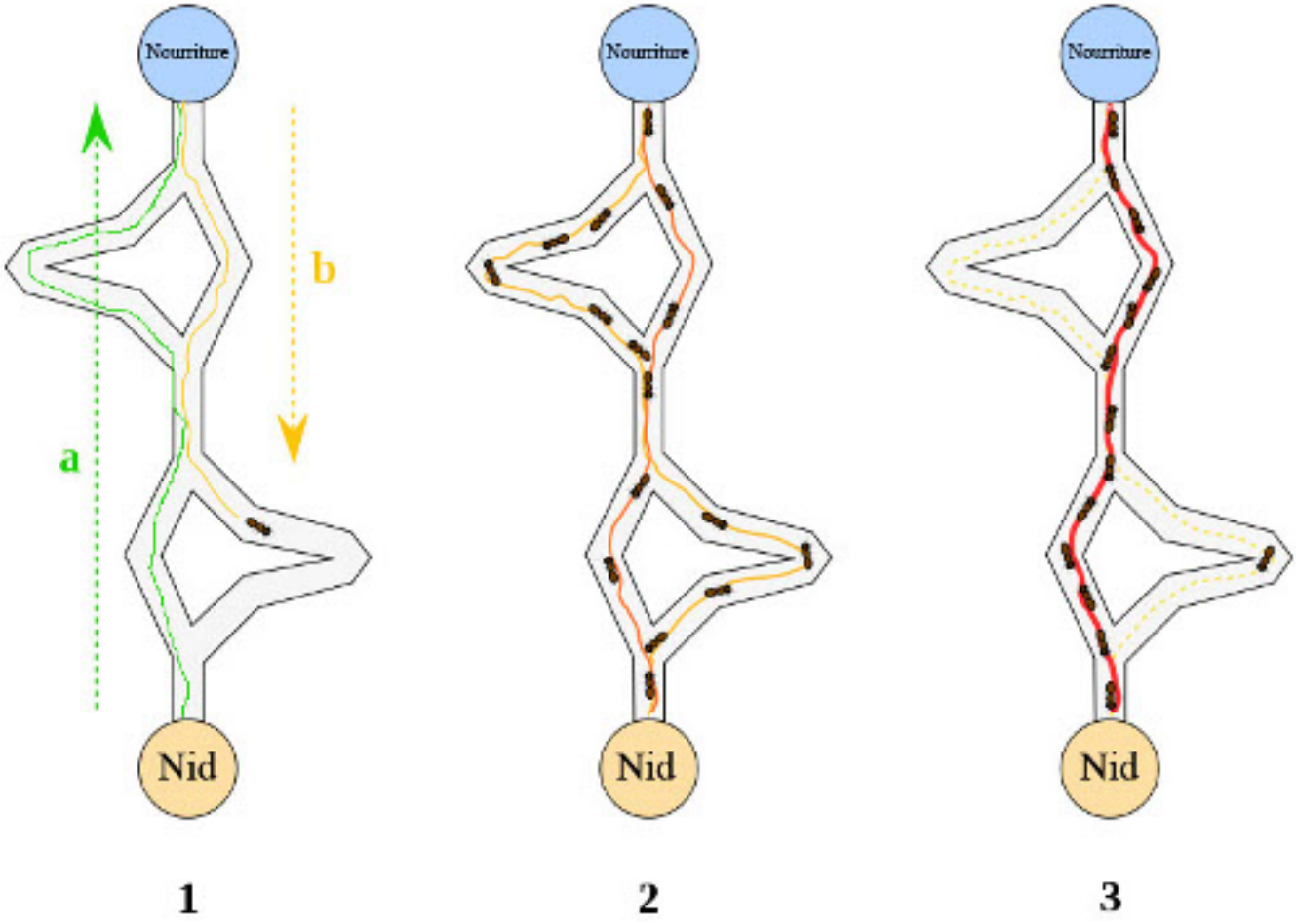


Figure 2.15: Representation of ants

Ants: Brod Sorting

This model is similar to the model previously quoted. It is based on a system of sorting concerning entities. A nest shelters various things inside, larvae, eggs, food. The ant colony keeps the entities sorted by kind. The behavior of ants goes this way:

- Ants have a random behavior around the nest.
- Ants locate nearby objects and memorize them.
- If an ant was carrying no element, it has the choice to collect the object or to leave it. The probability to collect an object decreases if the ant recently met similar objects.
- If an ant carries something, it can decide at any time to release this element. The probability that it releases, increases if the ant has recently met similar elements in the environment.

Termites

This model is based on the behavior of termites. These also use pheromones. Here are the rules followed by termites:

- Pheromones consist of physical waste.
- This waste is the material from which the termite mound is constructed.
- If there is no pheromone, ants move in a random way. If they detect pheromones, they will prefer to follow the strongest local pheromone concentration.
- At each time step, termites decides if they deposit pheromones.
- The rate of pheromone is decreasing according to time.

Wasps

The model based on wasps consists of several characteristics:

All the wasps are distributed in three groups.

- A single chief which distributes the various wasps in various groups.
- A group of foragers which has the mission to go hunting in order to obtain food.
- A group of nurses which care for the brood.

Every wasp gets three parameters. The first one concerns the strength of the wasp. It also represents the way it moves. The second parameter corresponds to a foraging threshold which determines the probability for a wasp to fetch of the food. The third parameter is associated with the brood. It allows to specify the demand in food. It allows to stimulate the foragers.

When two wasps meet, they are engaged in a fight. The winner of the fight is designated according to the strength of each wasp. Moreover, the demand of broods in food decreases if they have recently received.

Birds and Fish

This model is based on flocks of birds and schools of fish, which present the same coordinated behavior.
Indeed, they can turns together and avoid collisions with obstacles and between each others.

The human societies address similar problems, in air-traffic control and convoys of ships, but the human solutions depend on sophisticated communication an central coordination structures not available to birds and fish.

So, in order to answer to these troubles, the model follow three simple rules.

- maintain a specified minimum separation from the nearest object or neighbor,
- match magnitude and direction to nearby neighbor,
- and stay close to the center of the flock.

This model is a system as whole exhibits global coordination.
Indeed, although each entity's senses only the movements of it's nearest peers, its responses to these movements propagate to others.

Wolves

Chapter 3

Scenarios

We saw that the issue of this article is "how well scan an area?".
So the scenario is the reconnaissance of an area. It takes place in a square with a side length of 30 kilometers.
For this scenario, we use 10 UAVs and a command and control center (C&C). Each UAV starts at the middle of the south edge heading north near the C&C. The UAVs have to scan entirely the map once per hour.

For the reconnaissance data, to be of any use, it needs to be transmitted to the users that need it. In this scenario, it's the C&C which needs it. So each UAV need a communication path to C&C to transmit the data collected. They have to maintain a contact with the C&C, so they need to be close enough a neighbour UAV.
Fortunately a very simple model of communication is chosen for the scenario. UAVs within 8000 meters of each other can communicate with infinite bandwidth. If they are further away no communication is possible.

Concerning the reconnaissance scan, an image resolution of 0.5 meters is chosen. The scan area is 2000x1000 meters thanks to an 8 megapixel camera and the image proportions 2:1 (width:lenght).

Chapter 4

Needs Analysis

4.1 Functional Requirements

- The area coverage
  We need to cover the area the most efficiently and rapidly.

- The connectivity
  UAVs need to be always in contact with the C&C to transmit the information at any time.

4.2 Non-Functional Requirements

- No excessive use of bandwidth
  The bandwidth is a limited and a precious resource. Therefore UAVs have to used bandwidth the better possible to not overloaded her.

- Regurlarly updated the information
  UAVs transmit their information to the C&C and other UAVs when they are near . Thus, if a UAV have data much old, it is possible that he scans a part of the area already scanned. Hence, the data transmitted by UAVs have not to be older than prescribed and if each UAV has up-to-date information, the scan coverage will be more quickly.

- A robust model
  Lost or unaivable UAVs during a scenario not involved the good progress of the scan coverage. The resulting of a lost UAV should not degrade the final result.

Chapter 5

Schedule

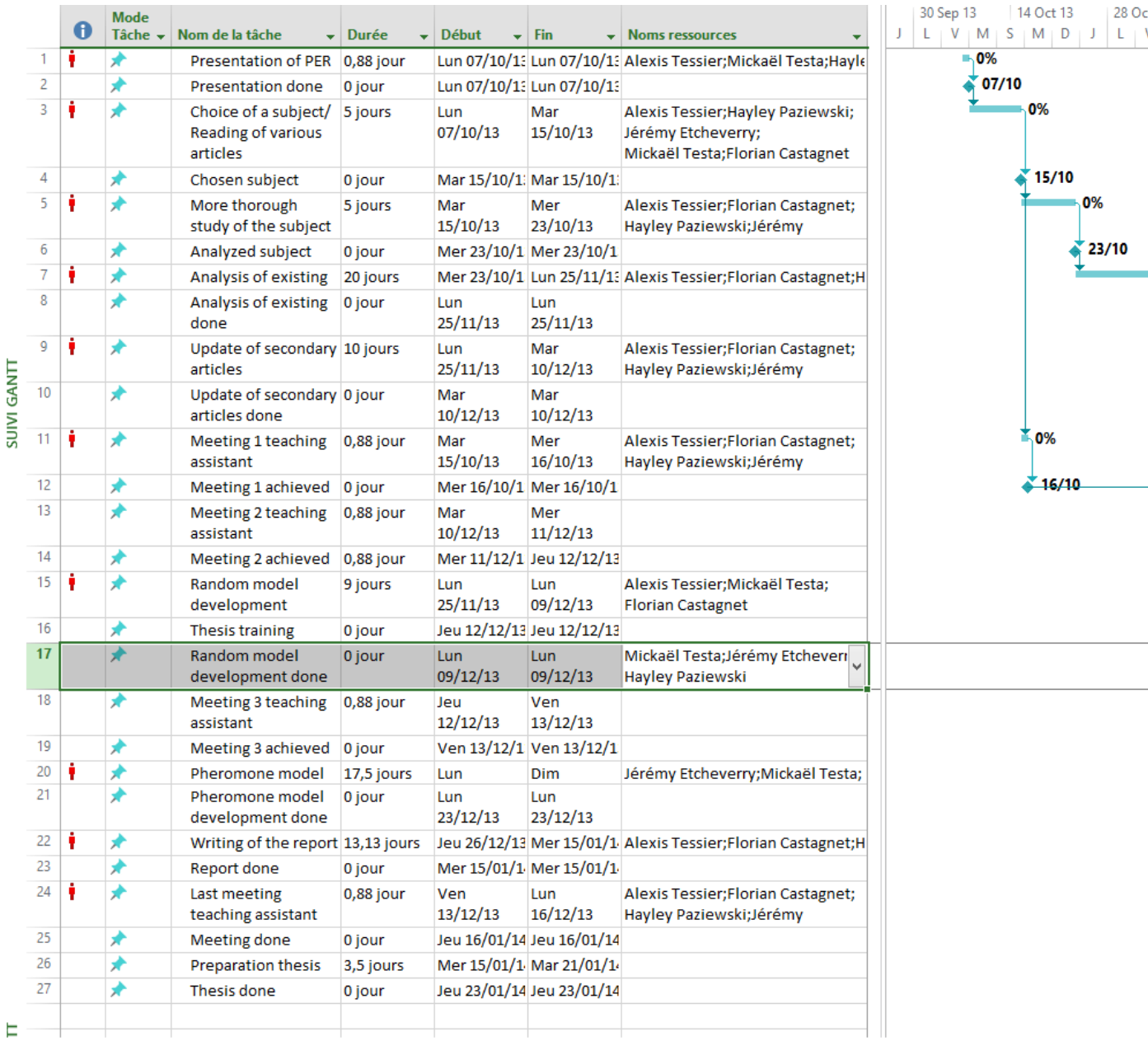
In this part, we are going to deal with the organization of the team on this project. TFirst, we identified the different tasks which will constitute this project. Thanks to elements identified previously, we made a Gantt diagram which is a tool used in project management, and allowing the affectation of a task for one person or a group of person, the time which this task will have to take. He allows to visualize the fulfillment of the tasks according to time.

5.1 Tasks List

A list of task was identified from the beginning by the project to be able to lead it most effectively possible from the beginning to the end.

- The choice of the subject. We took a subject which concerned drones because the majority of our team follow the subject Communicating Autonomous Systems.
- An analysis of existing concerning the communicating autonomous systems. We read about ten articles in touch with our main subject.
- An update of various articles previously studied is essential. Indeed, the speed of evolution of the technology today is so important that a written article two or three years ago may be out of date.
- The development of both present models in the studied article.
- The writing of this report.
- The preparation of the orals.

5.2 GANTT



	Mode Tâche	Nom de la tâche	Durée	Début	Fin	Noms ressources
1		Presentation of PER	0,88 jour	Lun 07/10/13	Lun 07/10/13	Alexis Tessier;Mickaël Testa;Hayle
2		Presentation done	0 jour	Lun 07/10/13	Lun 07/10/13	
3		Choice of a subject/ Reading of various articles	5 jours	Lun 07/10/13	Mar 15/10/13	Alexis Tessier;Hayley Paziewski; Jérémy Etcheverry; Mickaël Testa;Florian Castagnet
4		Chosen subject	0 jour	Mar 15/10/1	Mar 15/10/1	
5		More thorough study of the subject	5 jours	Mar 15/10/13	Mer 23/10/13	Alexis Tessier;Florian Castagnet; Hayley Paziewski;Jérémy
6		Analyzed subject	0 jour	Mer 23/10/1	Mer 23/10/1	
7		Analysis of existing	20 jours	Mer 23/10/1	Lun 25/11/13	Alexis Tessier;Florian Castagnet;H
8		Analysis of existing done	0 jour	Lun 25/11/13	Lun 25/11/13	
9		Update of secondary articles	10 jours	Lun 25/11/13	Mar 10/12/13	Alexis Tessier;Florian Castagnet; Hayley Paziewski;Jérémy
10		Update of secondary articles done	0 jour	Mar 10/12/13	Mar 10/12/13	
11		Meeting 1 teaching assistant	0,88 jour	Mar 15/10/13	Mer 16/10/13	Alexis Tessier;Florian Castagnet; Hayley Paziewski;Jérémy
12		Meeting 1 achieved	0 jour	Mer 16/10/1	Mer 16/10/1	
13		Meeting 2 teaching assistant	0,88 jour	Mar 10/12/13	Mer 11/12/13	
14		Meeting 2 achieved	0,88 jour	Mer 11/12/1	Jeu 12/12/13	
15		Random model development	9 jours	Lun 25/11/13	Lun 09/12/13	Alexis Tessier;Mickaël Testa; Florian Castagnet
16		Thesis training	0 jour	Jeu 12/12/13	Jeu 12/12/13	
17		Random model development done	0 jour	Lun 09/12/13	Lun 09/12/13	Mickaël Testa;Jérémy Etcheveri Hayley Paziewski
18		Meeting 3 teaching assistant	0,88 jour	Jeu 12/12/13	Ven 13/12/13	
19		Meeting 3 achieved	0 jour	Ven 13/12/1	Ven 13/12/1	
20		Pheromone model	17,5 jours	Lun	Dim	Jérémy Etcheverry;Mickaël Testa;
21		Pheromone model development done	0 jour	Lun 23/12/13	Lun 23/12/13	
22		Writing of the report	13,13 jours	Jeu 26/12/13	Mer 15/01/1	Alexis Tessier;Florian Castagnet;H
23		Report done	0 jour	Mer 15/01/1	Mer 15/01/1	
24		Last meeting teaching assistant	0,88 jour	Ven 13/12/13	Lun 16/12/13	Alexis Tessier;Florian Castagnet; Hayley Paziewski;Jérémy
25		Meeting done	0 jour	Jeu 16/01/14	Jeu 16/01/14	
26		Preparation thesis	3,5 jours	Mer 15/01/1	Mar 21/01/1	
27		Thesis done	0 jour	Jeu 23/01/14	Jeu 23/01/14	

Figure 5.1: Diagram of Gantt of our project

Chapter 6

Works Done

6.1 What we implemented

During two and a half months of this project, we implemented both models which were described in the article. As a reminder, these two models are a simple random and a model concerning pheromones. We also implemented the Random Waypoint model on the demand of our customers. In this section, we will explain the development work that we have provided and the different choices. We didn't find utility to make a UML diagram seen the simplicity of the architecture.

6.1.1 Architecture

Random Model

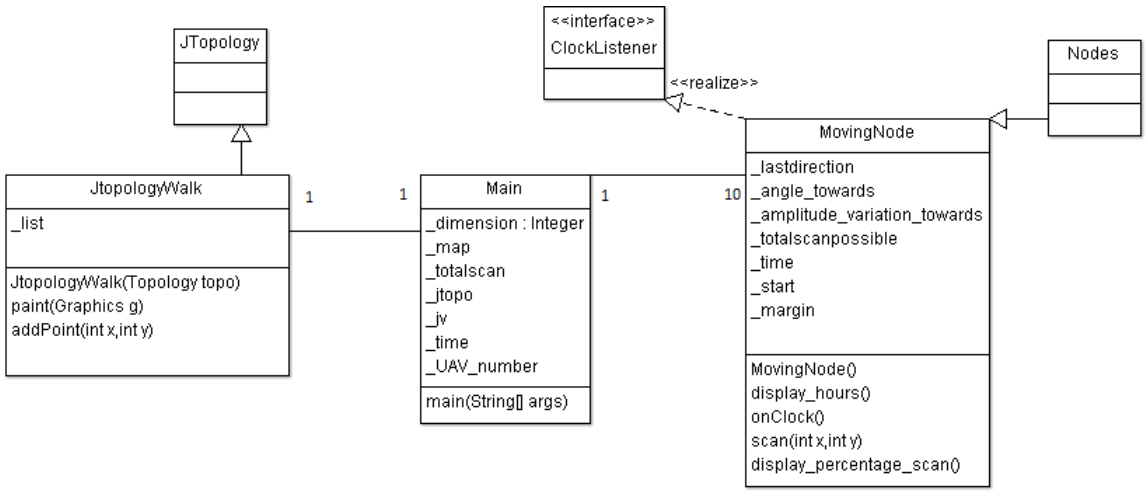


Figure 6.1: Diagram of class Random model

The description of all the classes will be made in the next section of this chapter.

Pheromone model

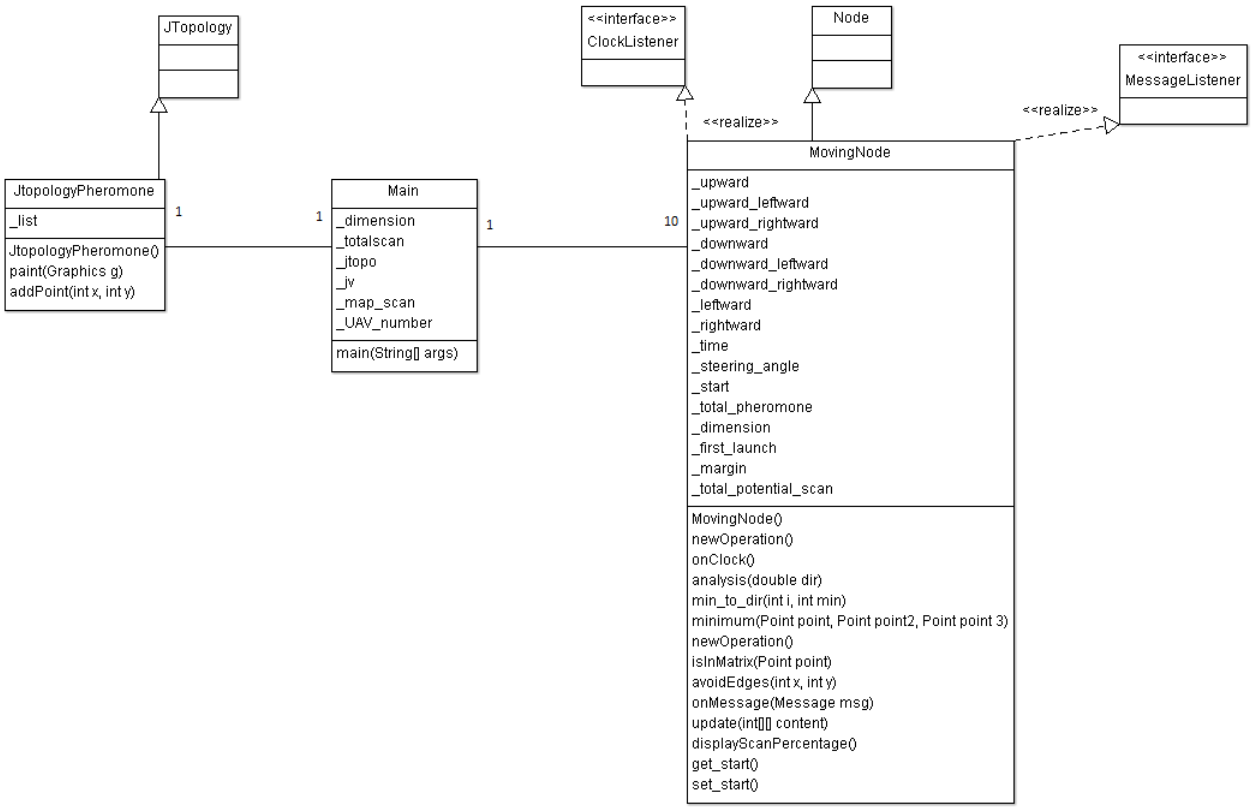


Figure 6.2: Diagram of class Pheromone model

The description of all the classes will be made in the next section of this chapter.

6.1.2 Random model

To implement this model, we needed three classes.
The first class, which is called *Main.java*, allows as its name indicates it, launching the program. It is in this class that we define the size of the window, the matrix which will serve to simulate the scan of a zone (all the nodes will have the same matrix), and the instanciation of the various objects coming of JBotSim library. We have for example, an object named *topo* which is a topology. This object is the basis for our simulator. It is to this topology that we are going to be able to add mobile nodes (here planes).

We also instantiated a Jtopology's object type. We will explain this choice during the presentation of entities.

The second class of our architecture is called *MovingNode*. It is in this class that will be handled the movement of the various nodes. That's why this class inherits from the class *Node* and implement the interface *ClockListesner*, both coming from the JBotSim librairies. It inherits from the class *Node* because planes will be represented by mobile node, so we need the characteristics of that class. Moreover, It implements the interface *ClockListener* because we need that our nodes move all the seconds, so we need a top of clock to realize it. We will have a listener for time , as well as a method *onClock* which will be called to every top of horloge.

This class contains a constructor by default, allowing to instantiate and to initialize the different variable, and to associate images with the mobile nodes (call of the method *setProperty*). The random model gets characteristic to have no communication between the different nodes. To realize it, we pass an argument of 1 in the method *setCommunicationRange*.

As indicated in the article, the nodes of the random model change actions every seconds in functions of the last undertaken action. As a reminder, here is the table of action for the random model:

Table 1. UAV random action table.

	Probability of action		
Last action	**Turn left**	**Straight ahead**	**Turn right**
Straight ahead	10%	80%	10%
Turn left	70%	30%	0%
Turn right	0%	30%	70%

Figure 6.3: Random model

In our implementation, we have a variable *lastdirection* allowing to know the last action which was made. We associated figures with the last actions. If the last direction was the left, then the variable *lastdirection* takes the value 1, if it was straight, then we associate the value 2, and if it was to the right, we associate the value 3.

To respect as much as possible the reality, we had to modify the management of the edges of the window. Indeed, originally in JBotSim, nodes can pass from an edge to the other one. For example, if they reached the left edge, they went to the right of the window, what is not possible in the real life. We blocked this problem by rectifying the position of the node, and by changing its angle of direction.

Each time a node scans a zone, it looks in the matrix if this position was already scanned (0 if the zone was never scanned, 1 otherwise). If it is, then it makes nothing, otherwise it puts the value to 1.

The third class of our architecture is called *Jtopology_Random*. It inherits from JTopology and is going to draw the scans footprint on the map. This class JTopology inherits from JPanel, and is situated in fact between a JViewer and a Topology.

6.1.3 Random Waypoint Model

This model is very similar to the previous. The only difference is their way to move.
In this model, the node choose one point randomly and move to it.
So the only modification compared to the previous model is the class *MovingNode* and more precisely the method *onClock*.
In this method, we choose a random point and we move the node until it. To do this, we change the direction of the node to the direction of the point chosen. When the node arrive at this point, we choose an other random point and so on.
In this model, we don't manage the edge of the window because all destination point are chosen on the window and so none UAV can go out the window.

6.1.4 Pheromone model

Concerning the architecture, the implementation of the model of pheromones is very similar. We find practically 3 even classy. Only the class *MovingNode* is really going to be different because the movements of nodes are going to depend on a lot of parameter. First of all, this class implements a new interface which is *MessageListener*. Indeed, in this model, nodes have to sent data each others (in this particular case their respective map).

The method which is going to change compared with the random model is the method *onClock*. Indeed, it is here that we are going to apply rules as described on the following image:

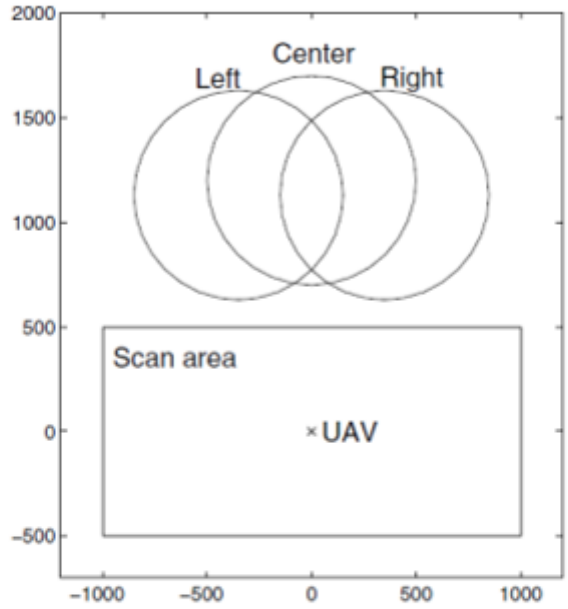


Figure 2. Pheromone search pattern

Table 2. UAV pheromone action table.

Probability of action		
Turn left	**Straight ahead**	**Turn right**
(Total – Left) / (2 * Total)	(Total – Center) / (2 * Total)	(Total – Right) / (2 * Total)

Figure 6.4: Pheromone model

We handled all the cases described in the article, meaning node looks at the values of pheromones in its left diagonal, in front of him and in its right diagonal.

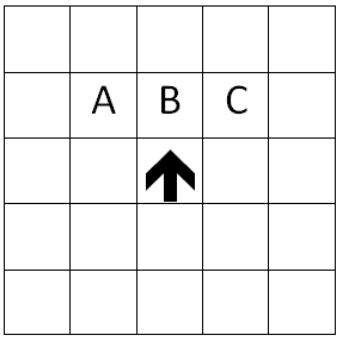


Figure 6.5: case 1

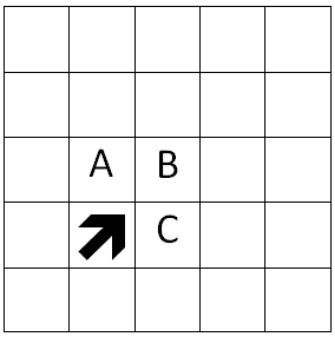


Figure 6.6: case 2

These both cases 6.5 and 6.6 show how a node scan the map.

- the area A represents the left diagonal of the node.
- the area B represents the front of the node.
- the area C represents the right diagonal of the node.

We handle the communication between each node with the *MessageListener* and the method *onMessage*. This method is called when a node do the method *send*. We have no destination in the method *send* to broadcast the message. We send message all ten top of clock to respect the conditions of the scenario of the article.

6.2 Difficulties Encountered & Solutions

The bigger difficulty encountered has been the reading of lot of articles in annexe of our main article. They included many pages and the reading of them in english which it took us a lot of time. We had to update each of them on internet in order to learn the evolution of the differents models, the technologies used, etc.

Concerning the implementation, we did not meet many difficulties. The only big problem is the display of the scanned zones. On the advice of Mister Casteigts, we had to create a class inheriting from JTopology and redefine the method *paint*. Indeed, the display refreshment of the scanned zones is a problem because we lost zones scanned previously. We created an ArrayList to save area scanned to redraw them in every times.

Chapter 7

Results

7.1 The article

7.1.1 Scan Coverage

The goal of the UAVs is to scan the full map once per hour. In theory, with a speed of 150 km/h, the maximum scan speed is 0.083 km^2/second/UAV. So with an area of 900 km^2, the fastest time to cover the full area is 18 minutes. The figure 7.1 and the figure 7.2 represent the coverage data from the mobility models.

Figure 7.1: Random mobility coverage

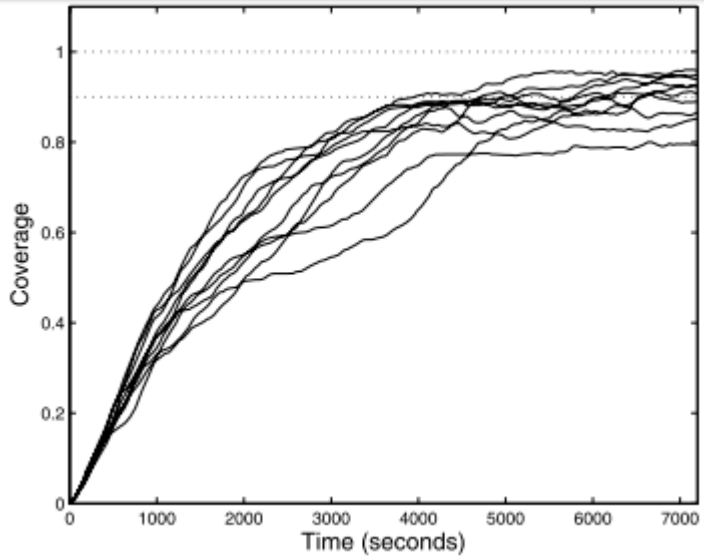
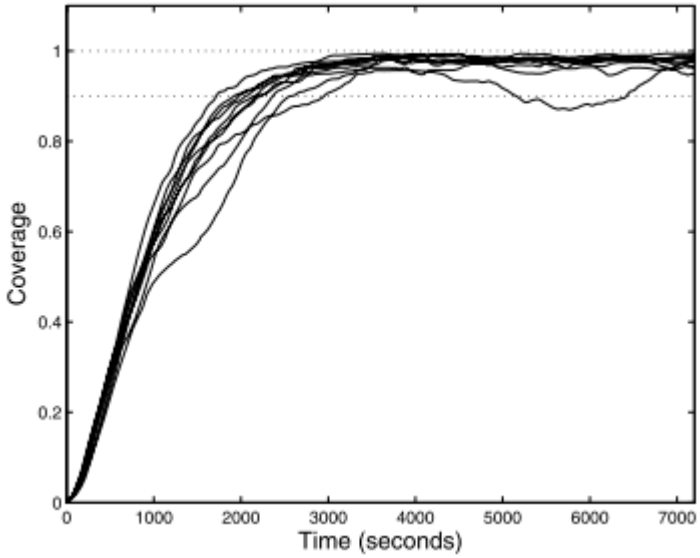


Figure 7.2: Pheromone mobility coverage



For the random model, we see that it need more than 83 minutes to reach 80 percents of coverage. Whereas the pheromone model reach the 90 percents in 60 minutes. Comparing the two models, the pheromone model has a much higher coverage rate.

7.1.2 Scan Characteristic

In Figure 7.3 and Figure 7.4, the solid lines represent the probability distribution of each models. This curve permits to calculate the probability of the next scan.
To know the probability of the next scan between the time t1 and t2, we have to calculate the area under the curve between t1 and t2.
So to meet with the requirement of one scan of the map per hour, the curve must be 0 at 1 hour. However none models reach 0 before one hour, because no model manages to achieve full coverage, the pheromone model manages well to avoid rescanning a recently scanned area. We can see that on the graphic : the median curve follows the dashed line at time between 0 seconds and 1000 seconds.

Figure 7.3: Random mobility

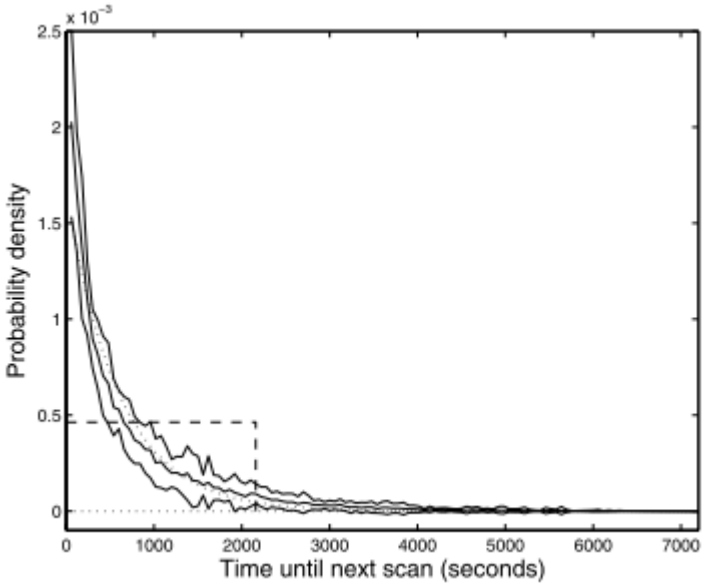
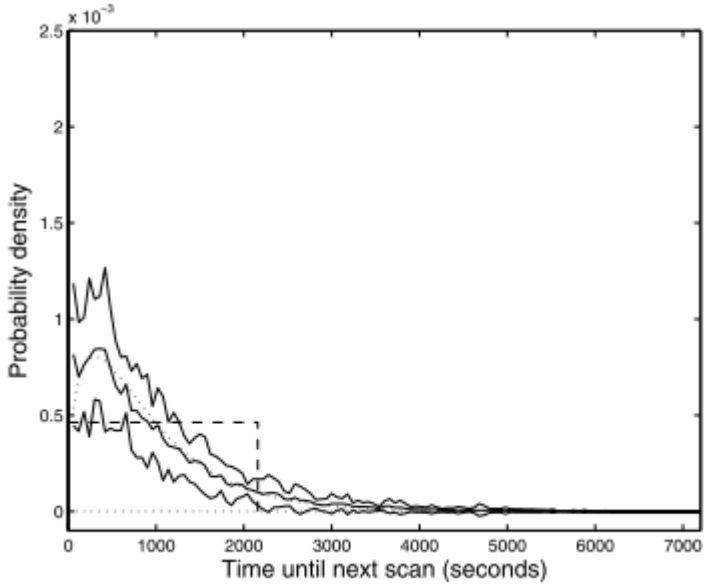


Figure 7.4: Pheromone mobility



7.1.3 Never scanned area

In this tableau below, we can see the results about the percentage of the map never scanned.

	Max	Median	Min
Random	16.2%	3.2%	0.5%
Pheromone	0.21%	0.03%	0.01%

It represents the maximum, median and minimum uncovered area for the ten runs. These numbers clearly show the ability of the pheromone model to cover the complete area.

7.1.4 Connectivity

Figure 7.5: Random. Number of UAVs in contact with C&C (max, average, min)

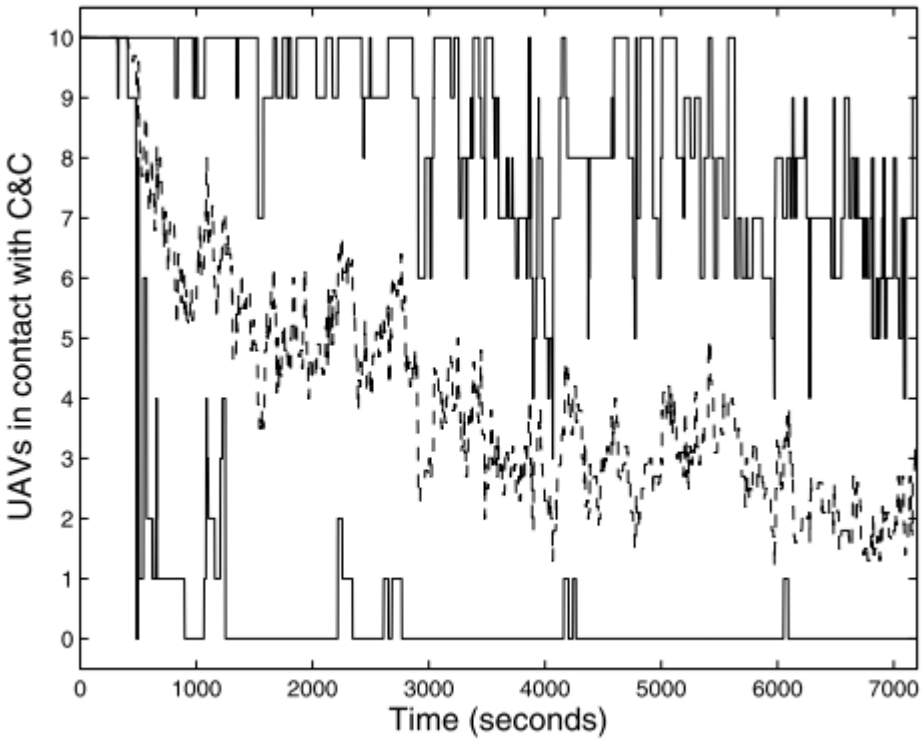
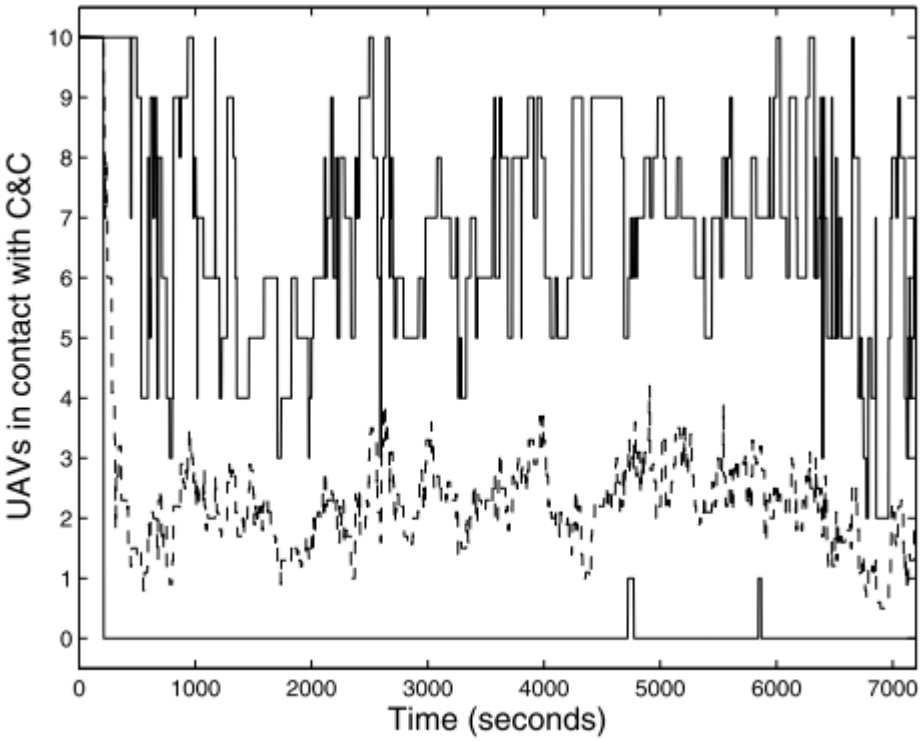


Figure 7.6: Pheromone. Number of UAVs in contact with C&C (max, average, min)



In Figure 7.5 and Figure 7.6,we can see the number of UAV wich can communicate with the C&C. The graphs show the maximum, average, and minimum of this number for the ten runs. We saw that both models don't provide good connectivity. There are not enough UAV to have a fully connected communication graph. Because of the pheromone logic that pushes the UAVs away from each other, this model have low connectivity. Whereas the random model have a high connectivity at the beginning of the run. Then with the random trajectory of each UAV, they move away from each others and finally this model finishes to have the same poor connectivity as the pheromone model.

Chapter 8

Tests

Chapter 9

Improvements

9.1 Mobility models

- In this article, they use The pheromone repel model wich had a bad connectivity. To improve the connectivity, we can add attractive pheromone. At regulary time, the C&C can add attractive pheromone in its place to force the UAVs to move to it in order to have a regulary update of the full map that the C&C gets.
- An other way to improve this model is to add more C&C on the area. Therefore each UAV has a map more often update.
- We can also split the map in equivalent part considering the number of drones. We give a different piece of an area to each UAV. To do that we can add attractive pheromone in these area. So each UAV scans their area and goes to the C&C to transmit his map.
- We can increase highly the connectivity adding others small UAV wich could maintain the communication with the C&C. These small UAV can make the communication path between an UAV and the C&C. Be aware of placing the small drones above the standard drones to avoid collisions.

Chapter 10

Development Environment and Conventions

In this part, we will see the development environment we used, and the programming conventions we've applied.

10.1 Development Environment

10.1.1 github

To write this report and to be able to implement both models most effectively possible, we used a tool of hosting and management of program which is called Github. It is a tools of versionning which allows the collaborative work and allows a simplification of the methods of work.
We used it throughout the project to put the summaries of articles that we read, the tasks which we had to make, this report or still the implementation.
Our Git repository is located at the following address :
`https://github.com/jetcheve/M2_PER_MMUAVGRA`.

Our deposit decomposes into three branches :

- A master branch which is general to the whole deposit.
- A branch called Develop. It is in this branch that there will be all the code for implementing different models. It also contains a test folder.
- An branch report, which as its name suggests, contain all the parts of our report and the pictures have inside it.

10.1.2 Eclipse

Eclipse is an integrated development environment for creating projects in any programming language. It is used to develop programs in JAVA, Android, C, etc.

We used Eclipse throughout the project implementation.

As a supplement to Eclipse, we used a library that is called JBotsim [2] proposed by Mr. Casteigts. This allows to simulate a dynamic network. This network is simulated with mobile nodes that interact. These nodes can send messages (in our case, maps of each UAVs).

We used this library because it is very easy to use, and it adapt well to the needs which we had.

10.2 Programming Conventions

First, we've choosed to used the Java Coding Conventions, which we can see in the following link `http://www.oracle.com/technetwork/java/codeconventions-150003.pdf`

Then, in order to create our documentation, we've used the Doxygen Convention, viewable here `http://www.stack.nl/~dimitri/doxygen/manual/docblocks.html`
We've relied heavily on this documentation and have mostly employed these protocoles below.

Doxygen Convention for classes

```
/**
* @class name of the class
* @brief Description of herself
*/
```

Doxygen Convention for methods

```
/**
* @brief Description of the method
* @param the parameters and their descriptions
* @return the description of what return the method (optional)
*/
```

Doxygen Convention for members

```
int var; /**< Detailed description after the member */
```

We've also resorted to programming conventions that we defined between us.
For example, when a part of a code, was not finished yet, we put the following lines above the concerning part.

Programming convention for unfinished code

```
/**
* @TO_DO
* Description
*/
```

We've also used a convention for the bugs found and wrote these protocoles, depending on whether the bug was resolved or not.
We used it, in line with the Bug Tracking of GitHub.

Programming convention for bugs

```
/**
* @BUG
* @Unfinished/finished
* Description
*/
```

To finish, we've created the five essential files for a project :

- INSTALL.txt : Installation instructions for the project,
- LICENCE.txt : Licence and copyright © of the project,
- README.txt : General description of the project,
- AUTHORS.txt : Authors of the project,
- MANIFEST.txt : Tree structure and files list of the project.

Chapter 11

Conclusion

This article shows that we can't have a good coverage with an adequate communication connectivity. We must find the balance between this two points to have the best model. The random model is simple but it has low connectivity with a bad coverage of area. The best model presented on the article is the pheromone model. It has a good scanning properties thanks to its pheromone repel. But like the random model, it has a low connectivity. A good connectivity is essential to collect data in a more efficient way.

We have seen that the pheromone model isn't perfect and however it has ideal characteristique that are not possible in real condition. Like the communication's range of each UAV is impossible in real life. They can't have a range of 8 km with illimited bandwidth. They have no lost packets, no contention, no overloads. With all these constraints, the connectivity of the pheromone model will be lower than those in article.
Both models can't be used to real scenario of reconnaissance.

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