UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

itee PhD information technology electrical engineering

DIETI UNINA

PhD Student: Fabrizio Tavano

DEVELOPMENT OF AN EFFICIENT STRATEGY TO LEAD A TEAM OF ROBOT WORKING FOR THE SANIFICATION OF THE RAILWAY STATIONS

Tutor: Prof. Vincenzo Lippiello

Co-Tutor: Dott. Riccardo Caccavale

Cycle: 35 - Academic year: 2020-21 - PhD Year: Second

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My background

- PhD student: Fabrizio Tavano
- DR number: DR993890
- Date of birth: 29/08/1981
- Master Science degree: Electronic Engineering University: Second University of Naples
- Doctoral Cycle: XXXV
- Scholarship type: no scholarship
- Tutor: Prof. Lippiello Vincenzo
- Co-Tutor: Dott. Riccardo Caccavale

Research field of interest

- The field of interest is the decentralized control of autonomous robots collaborating together to solve the same task.
- In order to find the better solution, the following arguments are studied:
  - Reinforcement learning: Deep Q-Networks
  - Model based control technics: Model Predictive Control

Summary of study activities

Title of course (Total number: 12)	Professor\University
SIDRA 2021 PhD Summer School (30 hours), titles: "**Game Theory** and Network Systems", "Modeling and Control of **Soft Robotics**"	University of Bologna
MSc course, title: **Intelligent robotics**	Prof. Alberto Finzi
MSc course, title: Image and **Video Processing** for **Autonomus Driving**	Prof. Luisa Verdoliva
MSc course, title: Image Processing for **Computer Vision**	Prof.Giuseppe Scarpa
MSc course, title**: Neural Networks** and Deep Learning	Prof. Giuseppe Prevete
MSc course, title: **Text Mining**	Prof.ssa Flora Amato
MSc course, title: Natural **language Processing**	Prof.Francesco Cutugno
Module: **Statistical Learning**	Prof.ssa Anna Corazza
MSc course, title: **human-robot** interaction	Prof.ssa Silvia Rossi
MSc course, title: **Fondamenti di Robotica**	Prof.Bruno Siciliano
Data Management	Prof.ssa Flora Amato
Ad hoc course, title: **deep learning and computer vision** for **autonomous systems**: focus on drone vision, imaging surveillance and cinematography	Prof. Ioannis Pitas, Aristotle University of Thessaloniki, CELLL Center for education and lifelong learning

Some significative titles of followed seminars in this year (Total number: 33)
Seminar title**: Artificial intelligence** and 5G combined with holographic technology: a new perspective for remote healt monitoring, lecturer: Dr.Pietro Ferraro, Dr. Pasquale Memmolo
Optimized **Graph Representations** for Right-Wing Reddit Community Using **Graph Neural Networks**, lecturer: Mr Mohammad Diaoulé Diallo, University of Bielefeld
Introduction to **Legged robots** and examples of IIT's Dynamic Legged Systems Lab, lecturer: Dr. Claudio Semini, Dr. Michele Focchi,
Introduction to **underwater robotics**, lecturer: Dr. Claudio Semini, Prof. Gianluca Antonelli
GDPR basics for **computer scientists**, lecturer: Dr. Rigo Wenning,
Exploiting **medical imaging** in the era of big data, lecturer: Dr Marco Aiello
Exploiting **Deep Learning** and Probabilistic Modeling for Behavior Analytics, lecturer: Prof. Giuseppe Manco
Seminar, title: The coming revolution of **Data driven** Discovery (a fourth Methodological Paradigm of Science), lecturer: Prof. Longo
Seminar title: Sadas Engine, **an innovative DBMS** for the **data warehouse**, great performance in the VLDB environment, lecturer: Eng. Luca De Rosa
Approaches to **Graph Machine Learning**; Lecturer: Miroslav Cepek–Oracle Labs

Study and training activities-credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	22.5	2.4	10	0	34,9
Bimonth 2	6	2	10	0	18
Bimonth 3	0	4.5	10	1 (25 hours)	15,5
Bimonth 4	12	2.8	8	0.6 (15 hours)	23,4
Bimonth 5	30	0	8	0	38
Bimonth 6	0	1	9	0	10
Total	**70,5**	**12,7**	**55**	**1,6**	**139,8**
Expected (in 3 years)	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

Study and training activities-credits earned

Year	Courses	Seminars	Research	Tutorship	**TOTAL**
	(credits)	(credits)	(credits)	(credits)	
I	**44,5** (min 20 - max 40)	**11** (min 5 - max 10)	**57** (min 10 - max 35)	**0** (min 0 - max 1.6)	**112,5**
II	**70,5** (min 10 - max 20)	**12,7** (min 5 - max 10)	**55** (min 30 - max 45)	**1,6** (min 0 - max 1.6)	**139,8**
TOTAL (ranges ref. in 3 years)	**115** (min 30 - max 70)	**23,7** (min 10 - max 30)	**112** (min 80 - max 140)	**1,6** (min 0 - max 4.8)	252,3

Courses for next year

Course	Professor
MSc course, title: **Control System** Design	Prof. Garone (ULB, Brussels, Belgium)
MSc course, title: **Optimization-based Control**	Prof. Garone (ULB, Brussels, Belgium)
SIDRA 2022 PhD Summer School	University of Bologna
MSc course, title: Data Mining	Prof. Longo (Univerisity of Naples Federico II)

Tutorship

In the period between 1.03.2021- 30.06.2021, I have actively participated to the correction of on-line exercitations and home-works for the training of the students for the following MSc courses:

- Robotic Labs: 20 hours
- Theory of Systems : 20 hours

For a total of 1.6 credits

A Multi-robot Deep Q-Learning Framework for Priority-based Sanitization of Railway Stations

Fabrizio Tavano

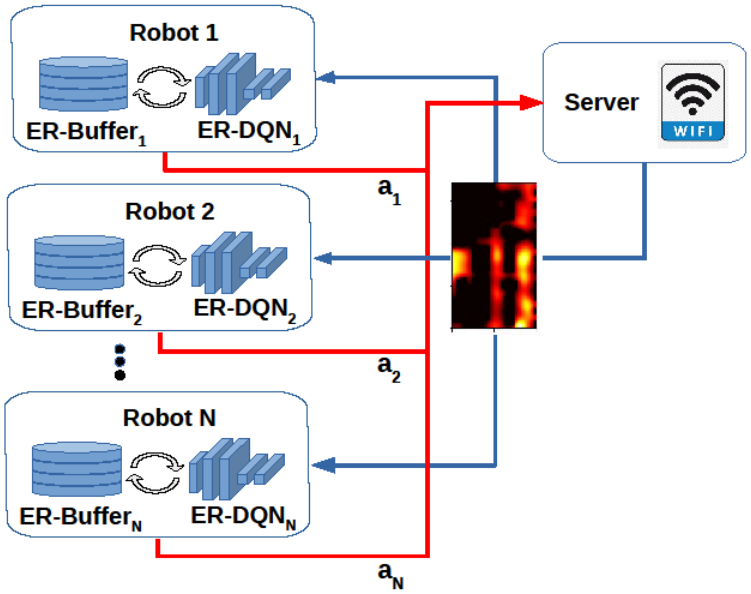
Our needs

- The role of railway stations in large cities is evolving: the number of services they offer is growing more and more. The stations are no longer simple nodes of the railway network, for the access to the trains as passengers, facilitating the intermodal road-rail exchange. The stations are now location of many other services, they have shops and catering activities, places for recreation and aggregation, environments suitable to organize public events. They are therefore strategic elements for the life of modern cities, which are increasingly popular. Modern society is increasingly open and connected, and the demand for transport is ever increasing. In this context, the railway sector is essential to respond to the new mobility needs.
- On the other hand, the probability of spreading diseases due to the presence of microorganisms (bacteria and viruses) between places of great population density, apparently distant between them, but indeed very connected by modern transport systems, is increasing more and more.
- Furthermore, it is fundamental and strategic that the Railway Transport Company and the Infrastructure Manager Company as Rete Ferroviaria Italiana, are equipped with adequate and modern tools to prevent future diseases from finding opportunities in the stations and on board of trains to spread and reach cities, even distant cities, destinations of the public transport service.

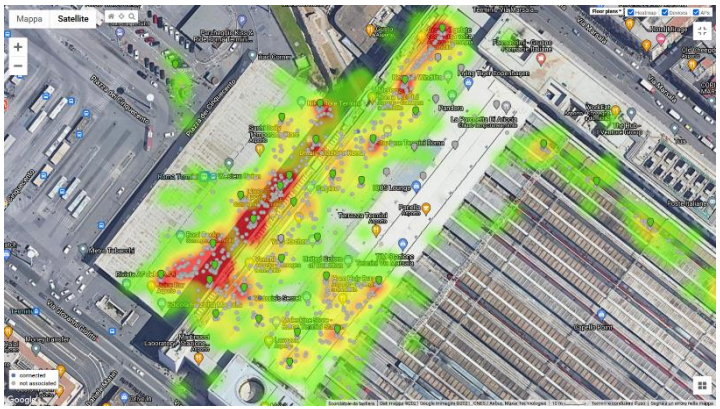
Our Architecture

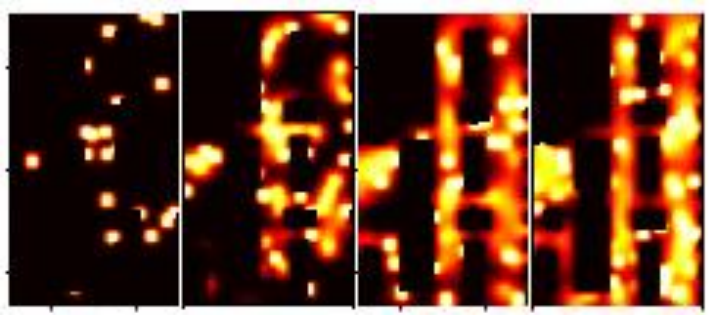
our solution for the sanitizing of the station is a distributed approach in which a server shares information as an heatmap, and the robots makes autonomous decisions

we have used a neural network for every robot, every robot has the vision of all the environment thanks to an heatmap shared by a server, and in the heatmap there is an indication of the common targets, represented by the peaks of the gaussian functions The state, that represents the input of the CNN is a 2 channel matrix 100x172x2 where each element has values in [0,1]; in the first channel there is a real number representing the risk of the location; each element of the second channel is comprised in {0,1}, in particular 1 for the robot position, and 0 otherwise.



The use of access points in the stations





- we will use a server system that will be able to recognize the aggregations of passengers.
- localization of the position of the aggregations is possible by identifying the positions of smartphones thanks to the GPS and the triangulation technique applied to WiFi signal between more than one access point present in the station.
- The team of robots will be driven in an appropriate manner to sanitize the environment in continuous manner during the day.
- The centralized strategy of cooperation will be chosen and optimized thanks to Model predictive control methods and Deep Q-learning methods

The Environment

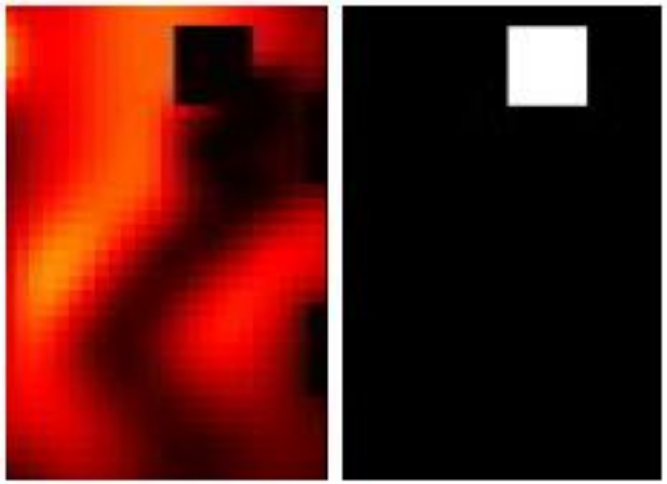
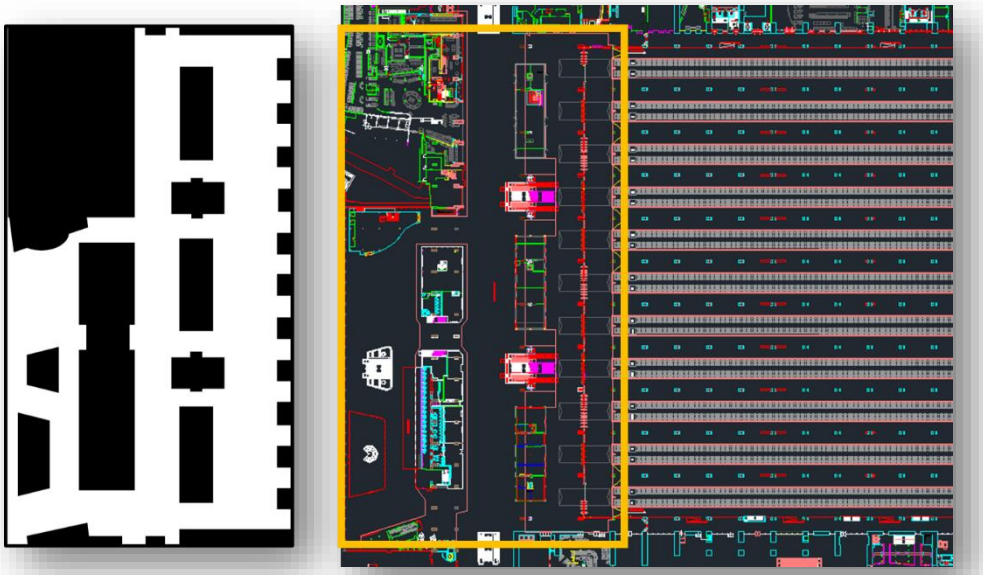


Figure at the right: example of the 2-channels matrix representing the priority distribution (left) and position and size of the cleaning range of a single agent (right)

on the left: the planimetry of the station, and on the right its conversion in an black and white image, preserving the same scale and proportions



Server-side learning algorithm

On the left the algorithm of the main process (the server) during the training phase. It is described how the main process serves to every robot. at line 5 we set in the heatmap at random positions, a random number of values "1"; the number is approximately 200, the values "1" correspond at the point in which there is the maximum risk of contagion. At line 4 the server receives the starting position of every robot in the heatmap; at line 5 the main process update the heatmap, considering the cleaning action of every robot stating from the knowledge of their positions;in the row 17, the server applies the gaussian filter to the heatmap; in the row 7 the main process sends the updated environment to the robots; the main process at the row 10 verifies if the target in terms of cleaning of heatmap is accomplished

Algorithm 2 Server-side learning algorithm

```
1:  procedure SERVER(k, M)
2:      while true do
3:          done = false
4:          (x_1, ..., x_k) = receive_positions()
5:          s = generate_random_state(M)
6:          for stp < max_step do
7:              send_heatmap(s)
8:              (x'_1, ..., x'_k) = receive_positions()
9:              s = update_state(s, (x'_1, ..., x'_k))
10:             if accomplished(s) then
11:                 done = true
12:             end if
13:             send_accomplishment(done)
14:             if done then
15:                 break
16:             end if
17:             s = apply_filter(s, N(μ, σ^2), M)
18:         end for
19:     end while
20: end procedure
```

Agent-side learning algorithm

On the right we show the algorithm used for the robots in the training phase. At the beginning in row 4 we do the reset of the initial conditions and we define an initial position for every robot; in the row 5 the robot sends its position to the server, our main-process ; in the row 7 the robot receives the updated environment from the server; in row 8 the robot does a change of position thanks to its neural network ;in row 9 it updates its own actual position in the second channel of the state, and it applies the disinfection on its copy of environment; in row 12, it calculates its own reward and it verifies if the heatmap is cleaned over a fixed threshold

Algorithm 1 Agent-side learning algorithm.

```
1:  procedure AGENT(i, M)
2:      while true do
3:          done = false
4:          x_i = random_position()
5:          send_position(x_i)
6:          for stp < max_step do
7:              s = receive_heatmap()
8:              a_i = select_action(s, x_i, ε)
9:              (s'_i, x'_i, r_i) = emulate_action(s, x_i, a_i, M)
10:             send_position(x'_i)
11:             done = receive_accomplishment()
12:             experience_replay(s, x_i, a_i, r_i, s'_i, x'_i, done)
13:             if done then
14:                 break
15:             end if
16:         end for
17:     end while
18: end procedure
```

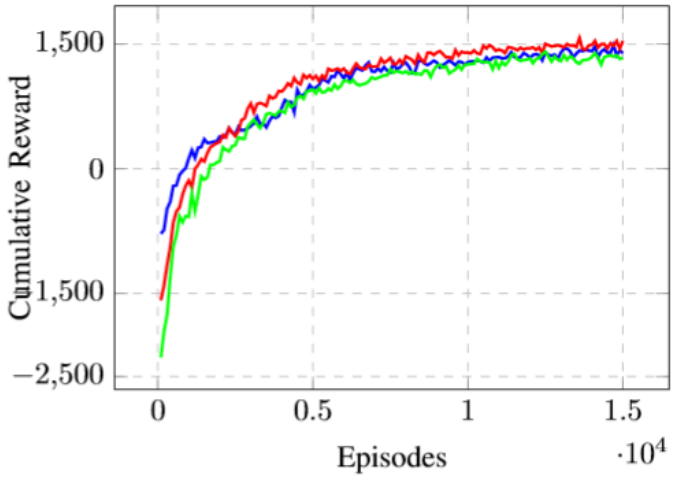
Server-side testing algorithm

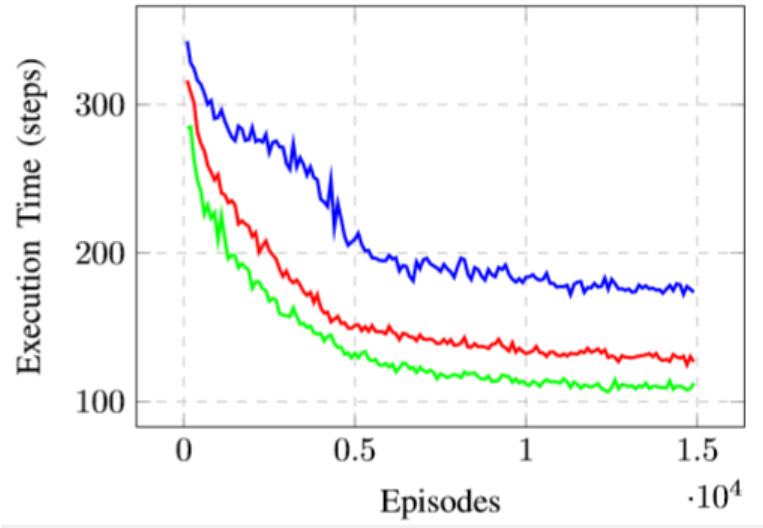
On the right side, we briefly describe the algorithm of testing of this solution; the main difference between the case studied in the training, here we change every 15 steps the position of all the clusters of the peoples, positioning them in another random state. Also the number of cluster may vary during the time

Algorithm 3 Server-side testing algorithm

```
30PercMax=MaxClust*30/100
MinValue=MaxClust-30PercMax
while Run until solved do
    NumberClusters=random(MinValue, MaxClust)
    server.createClusters(NumberClusters,Environment)
    robots.startProcess()
    server.receiveNewUpdateFromRobots(Positions)
    for timestep in range max episode do
        if (timestep is multiple of 15): then
            Delete.Clusters[];
            NumClusters=random(MinValue;MaxClust)
            server.Clusters(NumClusters,Environment)
        end if
        Heatmap=server.GaussianFilter(Environment)
        server.sendEnvironment.toRobots(Heatmap)
        server.verifyGoalSatisfied()
    end for
end while
```

Scalability of the solution





Future studies

- As future research activities, we plan to extend our pilot study by testing the proposed framework in a more realistic scenario, considering more complex robotic models and daily recorded data about people distribution in the station from the WiFi infrastructure and also to design a scaled environment with real robots.

- Furthermore, multi-agent strategies including teams of heterogeneous robots with different cleaning capabilities are currently under investigation. A robot in our experiment, doesn't know the position of the other robots that collaborate with it but their paths. It is also interesting to develop a solution in which robots have different approaches and different instruments for the sanitizing for the environment. Our solution implemented with a dedicated neural network for each robot is studied for this scope.

- It will be compared also the decentralized approach of a Buffer replay DQN, where every robot has its own neural network, with the centralized one, with one network that select the actions to do for every robot.

- A centralized strategy of cooperation will be chosen and optimized thanks to Model predictive control methods in alternative to Q-learning methods. In this manner, it will be possible to do a comparison between the results obtained by the adoption of model-based methods than model-free reinforcement learning algorithm methods.

Products

[P1]	Riccardo Caccavale, Vincenzo Calà, Mirko Ermini, Alberto Finzi, Vincenzo Lippiello and Fabrizio Tavano: title: “A Multi-robot Deep Q-Learning Framework for Priority-based Sanitization of Railway Stations”; AIRO 2021: 8th Italian Workshop on Artificial Intelligence and Robotics of the 20th International Conference of the Italian Association for Artificial Intelligence (AI*IA 2021),online, December 1st-3rd, 2021

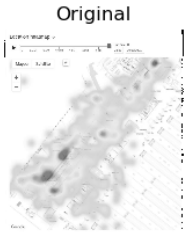
A Multi-robot centralized Framework for Priority-based Sanitization of Railway Stations using model predictive control method

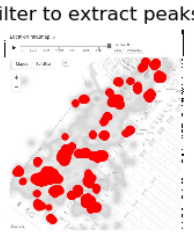
Periods abroad and/or in international research institutions: 15.09.2021 - 15.12.2021

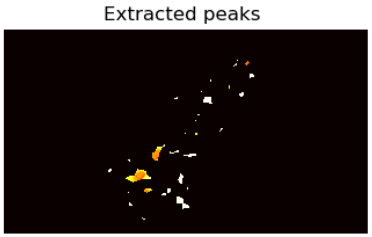
Université Libre de Bruxelles, Département : Service d'Automatique et d'Analyse des Systèmes: Prof. Emanuele Garone

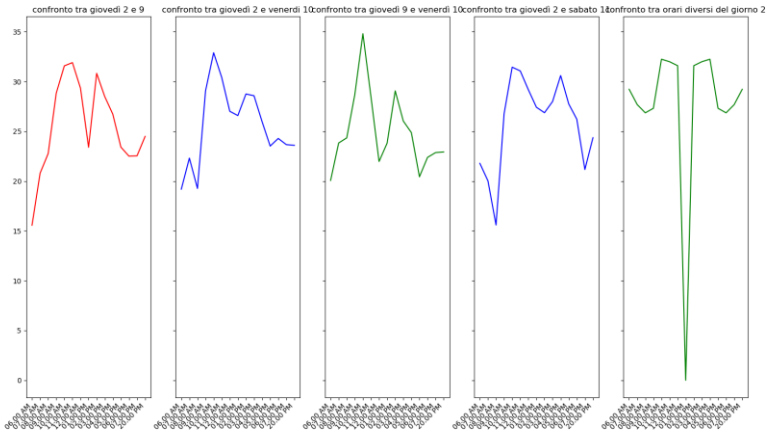
Università degli studi di Napoli "Federico II", Dip. DIETI: Prof. Vincenzo Lippiello, Dott Riccardo Caccavale, Fabrizio Tavano

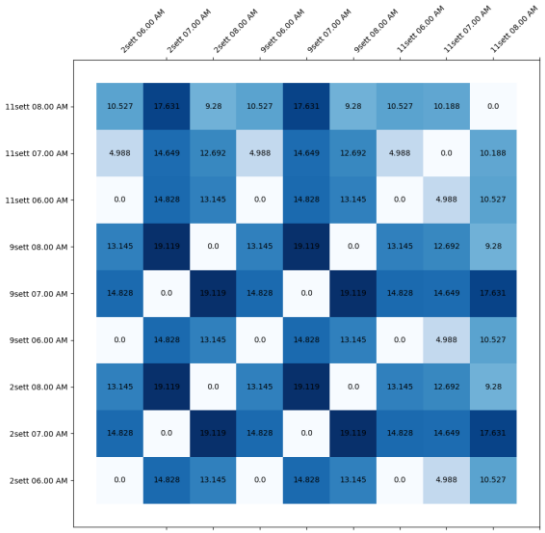
The extraction of data











The Model

$$\hat{x}_z(t+k+1|t) = \alpha\hat{x}(t+k|t) +_z k\hat{h}_z(t+k|t) - \hat{u}_z(t+k|t)$$

$$\hat{\gamma}_z(t+k+1|t) \in \{0,1\}$$

$$\sum_{z}^{N_z} \hat{\gamma}_{i,z}(t+k|t) = 1$$

$$\hat{h}_z(t+k+1|t) = \begin{cases} h_z(t) & k = 0 \\ \hat{h}_z(t+k) & k > 0 \end{cases}$$

$$\hat{\gamma}_z(t+k|t) \leq \sum_{z}^{N_z} \hat{\gamma}_{i,z}(t+k-1|t)$$

$$0 \leq \hat{u}_z(t+k|t) \leq \alpha\hat{x}_z(t+k|t)$$

$$\hat{u}_z(t+k|t) \leq M \sum_{z}^{N_z} \hat{\gamma}_{i,z}(t+k|t)$$

i= $1 \dots, N_R$

z= $1 \dots, N_z$

k= $1 \dots, N-1$

Mixed Integer Linear Programming (MILP)