Dynamic patients scheduling in the Pediatric Emergency Department

Sara Ben Othman[1], Nesrine Zoghlami[1], Slim Hammadi[1], Alain Quillot[2], Alain Martinot[3], Jean-Marie Renard[4]
[1]LAGIS UMR CNRS 8219 Ecole Centrale de Lille – France; [2]LIMOS UMR CNRS 6158; [3]PED of CHR Lille;
[4]EA2694 University Lille 2

Abstract—**D**ue to the complexity of Pediatric Emergency Department, health care management has attracted the attention of many researches which has led to intensive research in agent technology. Multi-agent systems seem to be an effective approach to design complex distributed applications. As the structure of hospitals is divided into several autonomous and ancillary units, we propose a new approach integrating jointly agent-based modeling and optimization tools. In this context, mobile agent paradigm is also very efficient once used through an optimization approach. In this paper, we suggest a three-level agent-based architecture to solve a distributed scheduling problem for resources allocation during patient journey. Our interest is minimizing the waiting time of patients to improve the quality of care process management as well as optimizing resources allocation. This contribution is included in the project ANR HOST (ANR-11-TecSan-010).

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I. Introduction

Emergency services have a critical mission in health care facilities. They feature the ability to satisfy the different needs of every patient. In addition to the purely medical terms, emergency medicine requires logistics (having the right equipment and the right medical staff at the right time and the right place) [1] and cooperation with other organizations. This may involve modeling and simulation concepts necessary to control and optimize patients flow. Planning and resources scheduling are also responsible for performance management and system control.

Health care facilities are facing more and more difficulties to manage the rising patients flow. In emergency departments, these difficulties consisted of overcrowding caused by chaotic patients' arrivals. Indeed, several studies have shown that one of two emergency services work in overdrive, which means that all patients do not have the privilege of being supported in optimal conditions with extended waiting times [2]. Emergency services can be exploited in an optimal way by an improvement in the services provided to patients and operating costs reduction. Indeed, patient waiting time improvement is a critical performance indicator related to the quality of care in the emergency department settings. This parameter has also an influence on costs.

Emergency Logistics system refers to a set of logistics elements which interact and coordinate with each other in order to complete emergency logistics requirements [3]. Therefore the system relays on a new set of distributed applications using a huge amount of data spread on different sites geographically separated). In such systems, data may undergo various simultaneous actions (requests, storage, update, etc.) which requires the access to different remote information sources. This dynamic, distributed and open aspect of the problem can be treated through different interacting individual entities. Thus, Multi-Agent Systems (MASs) have shown their relevance to this complex distributed applications design [4]. The concept of agent is not only an efficient technology, but it is also a new paradigm for software development in which the agent is an autonomous entity operating in a dynamic environment [5] and interacting with other agents using languages and protocols.

In addition to the distributed aspect of the studied problem, in the PED, actors behave in a critical and stochastic environment where an optimal solution must be deployed as quickly as possible in order to avoid the dramatic consequences especially on patients.

In this context, mobile technology can be a major advantage along with the artificial intelligence in the optimization of patients scheduling due to their adaptability and efficiency in heterogeneous and dynamic environments. The main objective of mobile agent (MA) paradigm to navigate through system's functions and also to extend its functionality by supporting disconnected operations. When the active mobile execute a remote operation, it disconnects the client and reconnect later to retrieve the results [6].

This option is based on the ability to move according to their own needs to best accomplish accorded tasks. In fact, medical staff which is the most critical resources can be treated carefully using mobile technology. The goal here is to simulate medical staff behaviors in the PED using MAs which, unlike "stationary" agents, have mobility. Certainly, these agents may move from one medical team to another, operating alternately on different patients, according to the skills required for the corresponding treatments. The paradigm of MA has been discussed in many studies. They are shown to be efficient [7] [8] [9] [10]. In this paper, we propose a proficient using of MA paradigm through a MAS designed for patient journey management where actors provide smart negotiation in order to execute and control patient's treatment tasks scheduling. More precisely, our study presents a set of tools and approaches for optimizing patients flow in a PED. Our goal is to model and implement a robust system for patients' treatment which is able to support a huge number of simultaneous requests, optimizing the services management, in order to satisfy patients with minimum costs and respecting emergencies degrees. In fact, we will detail the optimization models we used for the entire treatment of patients in the best conditions based on needed resources scheduling such as medical staff, beds, medicines, etc.

We will go through decisions regarding patients' emergency degree, resources availabilities and costs as well as the choice of medical staff based on their skills and planning. The presented solution comprises the use of a three-level agent-based framework including an optimization and negotiation scheme to resolve resources and patients scheduling.

This paper is organized as follows: a general formulation of the problem is illustrated in the following section. After that, an overall architecture of the MAS is proposed in section 3. The global scheduling approach is given in section 4. Experimentation and results are given in section 5. Conclusion and possible future works are addressed in last section.

II. Problem Description

During periods of peak activity, the PED, main entrance of sick children in hospital regardless their severity, overflows. The waiting room is not large enough, parents crowded into the narrow corridors of the service with their infants and waiting time dramatically increases. The service then switches into a new phase of operation, which we call "overcrowding" to streamline the flow of patients.

The idea is to get a rigid and theoretical framework for the service operation that would delight probably a specialist bureaucratic organization, but who has the terrible drawback of "waste" of resources. Thus, during peak activity, the medical staff takes the initiative to commandeer randomly all available resources, regardless of their theoretical characteristics.

The main interest of the PED is to satisfy patients, respecting responses delays according to emergency degrees and minimizing treatment costs; the problem to be solved is to ensure patients care quality as taking into account the severity of their pathologies. The main goal of our work is to manage patients flows by supporting and prioritizing the most serious cases. Care must mobilize both human and material resources in relation to (/with) their availabilities. Medical staff should be deemed "most expert" for a given care task to get allocated for treatment tasks.

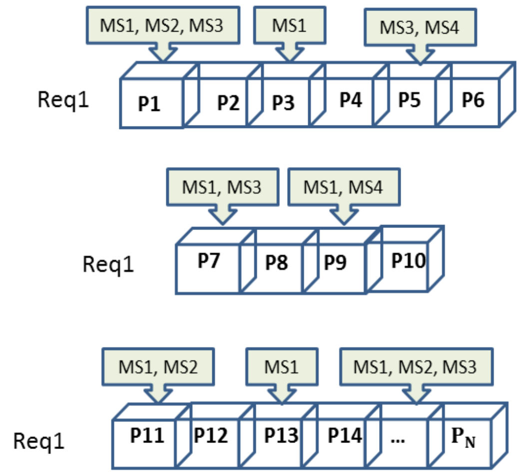

Figure 1: Medical Staff movement

The integration of mobile paradigm into our software agent gives the possibility to migrate towards the different boxes of the PED where patients are waiting for treatment and which can receive mobile entities (Medical Staff). In our proposed system, we use mobile medical staff agents to travel through the PED architecture to treat patients and to collect intelligently needed information related to patient health state in order to update the system data.

A task can belong to one or various patients. Medical staff agents receive many requests for different patients' treatment and according to their availabilities and to the emergency degree of patients they go for their treatment in the different boxes of the PED.

The reliability of the services delivered by the PED requires providing the necessary equipment to meet the requirements of the emergency mission. For the material resources, the issue is to deliver the resources avoiding stock-outs that can paralyze the functioning of whole the PED. This is called the procurement policy. It requires knowledge and total control of treatment time and amount of resources to allocate. So delays should be predicted and resolved earlier to minimize penalties and resources quantities should be optimized to avoid stock-outs and high wastage rates. On the other hand, before assigning one of the medical staff for patient treatment, a whole study should be done. Indeed, each medical assistant must be qualified to be charged of patients. Their availabilities must also be taken into account and their planning should be optimized by reducing their idle time.

The main concern is to satisfy the demand of the different actors of the studied health care circuit by providing efficient management and high care service level. Accuracy is one of the key objectives of the operations administration in health emergency institution management.

III. System Architecture

In a scheduling problem, four basic concepts are involved: tasks (or Jobs), resources, constraints and objectives. In our case, to execute patients' treatment tasks we have to consider the resources (medical staff, boxes, beds, medicines, etc.) to assign, time needed for task execution which depends on the emergency degree of patients. Additionally, we have to take into consideration some constraints such as waiting time and some objectives like costs minimizing as well as the complexity of the environment characterized by uncertainty and large number of actors in case of an overcrowding situation that make the scheduling task in emergency health care management highly complex.

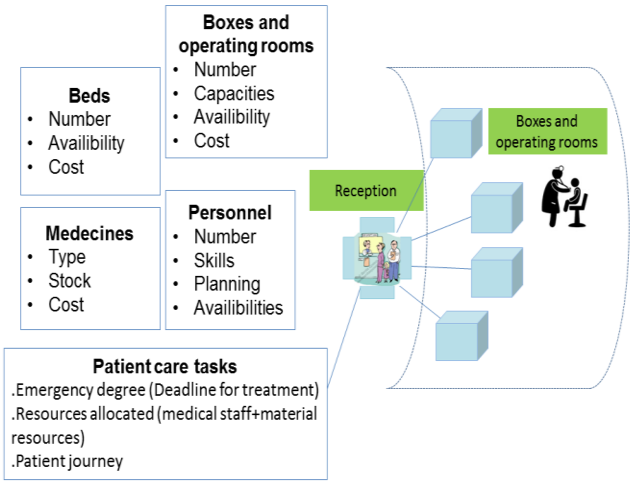

Figure 2: Typical model of a patient treatment scheduling system

We propose to consider each actor of the PED as an autonomous agent, able to interact with other actors [11]. Our proposition is to resolve the problem described previously through a system based on the coordination and cooperation between different kinds of software agents.

- Gui Agent (GA): This agent interacts with system users particularly the medical staff of the PED allowing them to know different demands sent to them as well as patients monitoring and the global state of the PED including the number of patients waiting, so they manage requests, go for patient treatment and then update the system data. When a patient arrives to the PED, an agent Home Agent (HA) responsible receiving the patients and their orientation and for the pathology identification is created. HA has all the skills required by the rules of registration plan, medical diagnosis plan and patient orientation plan. It deals with the formulation of the problem and then sends it to the Identifier Agent. This corresponds to the creation of a medical record through the Identifier Agent (IA) triggered by an administrative nurse.

- IA: it receives the different information from HA about the medical problem and identifies the skills needed for the treatment referring to the medical protocols. It consults the database of the different pathologies and the needed resources for their (patients') treatment.

- Scheduler Agent (SA): This agent has to optimize the choice of resources for patients' treatment taking into account some of the constraints of our system. It has to assign resources to patients' treatment tasks minimizing total cost and patients waiting time in order to respect emergency degrees. First of all it organizes the queue of patients who need treatment taking into account their emergency degree then it assigns resources to different task.

- Resource Agent (RA): this agent is responsible of the monitoring and management of different resources available for treatment tasks. It also detects whenever there are stock-outs of medicines and informs the user through the IA about requested supply.

- Monitoring Agent (MoA): this agent is notified for every taken decision and every task completed. It represents the coordinator between all software agents and an informer for the physical agents about actions and patients status.

- Integration and Evaluation Agent (IEA): this agent is responsible for the whole system performance control. It calculates the performance indicators of the system such as waiting time of patients and treatment costs in order to evaluate the overall schedule of patients in the PED.

- Medical Staff Agents (MSA): An agent MSA is a mobile software agent which can move intelligently from one treatment room to another in the PED in order to treat patients. It is characterized by two variables (skills and availability). This special kind of agent is composed of data, states and a code and has a smart behavior. Once MSA achieves a treatment task it can shift to another treatment room for a new task execution. Therefore, the agent SA must take into account this aspect when assigning human resources to tasks. Each task represents a service which can be performed by different possible MSAs, with different cost. To respond to tasks, it needs data about MSAs availabilities and available skills through the RA. Therefore, the SA agent must optimize the assignments of resources to tasks. For this assignment problem, we propose a three-level architecture as an optimizing solution based on the alliance between MASs and optimization tools. This architecture is described in the next section.

IV. THE AGENT-BASED DISTRIBUTED SCHEDULING SYSTEM

The system algorithm created for the scheduling based on interacting agents is as follows (Figure 3):

a. Once a patient arrives, we create our system's agents; HA is created for patient receiving and orientation and also for pathology identification. After registration, the information about patient is passed to MoA and to the IA.
b. The IA establishes which kind of resources is necessary for patient's pathology treatment using data histories. In addition to the material resources, it identifies the needed skills for every treatment task. Then, the SA is notified of information about material and human resources to be allocated.
c. SA treats the patients care requests received and asks for resources allocation from RA.
d. RA uses patient and pathology information received from IA to allocate the needed resources for the SA to start the scheduling of treatment tasks.
e. SA then goes for tasks scheduling. If it is about human resources, it identifies the needed skills for every task and medical staff availability. Patients' emergency degrees are given priority in this

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schedule. SA notifies the MoA and the IEA of the schedule generated for patients treatment.

f. IEA uses performance indicators for the global schedule evaluation.

g. MoA control the patients' physiological signs and location.

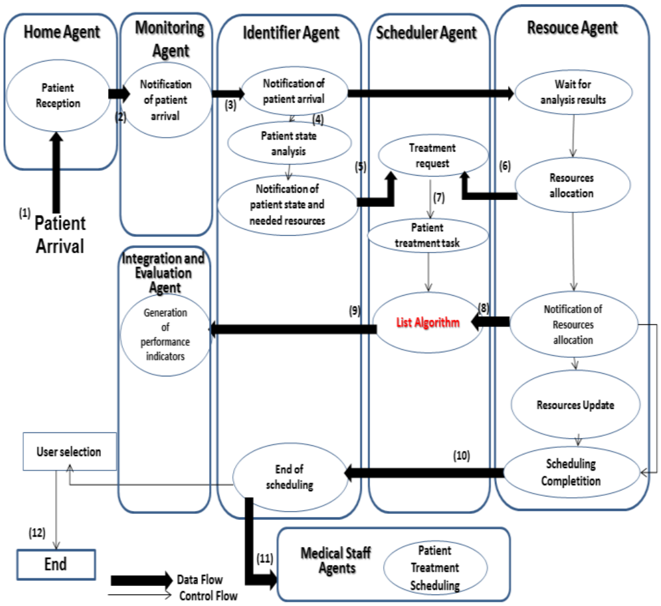

Figure 3: The Synchronized Distributed Patients Scheduling

A. A three-level agent based architecture

There are several scheduling optimization algorithms that can be involved in scheduling applications. But we can't find an agreeable and efficient scheduling strategy that is common to each and every patient's treatment tasks. In addition, resources in health care field are various and for each type we have to choose a different algorithm. In fact, operating rooms can't be scheduled like human resources for example. These are different and their differences are due to their skills. Thus, taking into account the characteristics of each type of resources, we propose a three-level framework.

Figure 4 shows the three levels representing the architecture suggested. The main level contains the MAS modeling actors involved during patients' journey. In this level agents are collaborating and negotiating in order to make decisions on scheduling strategies. The made decisions depend on data received from the bottom level (PED). The higher level contains scheduling optimization tools including different mathematical models.

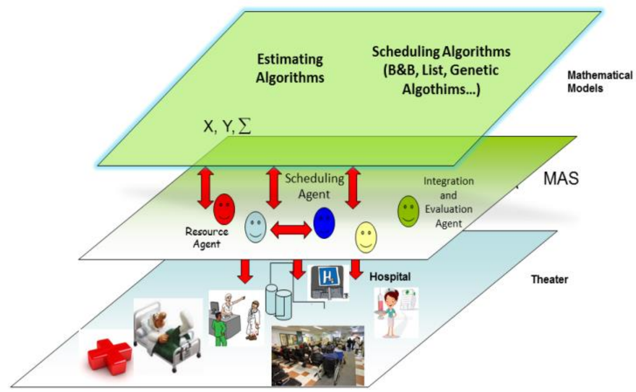

Figure 4: A three level scheduling architecture

As agents are autonomous entities characterized by decision-making capabilities, we propose to implement in this level a set of scheduling optimization algorithms, and according to the complexity of the situation, agents evaluate the global preference of a proposal to find out which scheduling algorithm should be used in order to better respond to the needs of lower level. The global preference is based on the performance indicators calculated.

The assignment of resources is an NP-complete problem. This complexity makes difficult the development and use of schedules planning systems generation. Planning system must consider organizational, treatment methods of resources and legal programming rules and individual preferences (in case of human resources scheduling).

B. Agent-based algorithm for patients scheduling

To execute treatment tasks, agents may decide to go for list algorithm, particularly suited to the studied system due to its dynamic priority rules. This algorithm is characterized by its flexibility and is easy to implement in real time. The problem is solved by static or dynamic priority rules.

The standard of this approach is to perform a scheduling of treatment tasks using lists algorithms based on dynamic priority rules. Specifically, at a given time T_0, among the ready treatment tasks to execute, the task of highest priority is scheduled. More generally, list algorithms develop first a priority list, which is then used to build a solution. In our problem the priority rule is dynamic. It is chosen by HA. Depending on the pathology and the emergency degree, it may be the smaller latest start date or lesser execution time.

The objective is to reduce waiting time of each patient; the objective function is as follows:

$$Min\ (\sum_{j=1}^{l} \max(0, c_j - d_j))$$

With:

- c_j = the completion time of the treatment task t_j
- d_j = the theoretical treatment time for the task t_j
- l= the total number of treatment tasks.

```
List Algorithm
   In:   T   (set of tasks to schedule)
   Out:  S
Begin
  S={} ;
  While T ≠ Ø (set of ready tasks T is not empty) do
        Begin
           Determine among the set T, the task t_i of
           highest priority;
          S: = S ⊕ t_i
        End
End
End
```

S is a sequence of partial (or total) solution for tasks scheduled.

S = ti ⊕ S; means to insert the task t_i in the sequence S, in the position intended by the scheduling.

C. *Mathematical Formulation of the scheduling problem*

The main concern of our proposed system is to satisfy the patients' needs, respecting emergency degrees and minimizing their costs and waiting times. At first, patients' treatment schedules are built by assigning material resources and medical staff to the needing patient. Then, performance indicators are generated to evaluate the overall performance of the PED and to identify the assignments that need to be readjusted, in order to get at the end patients satisfaction and safety as well as medical staff idles and overdrive elimination.

A patient is satisfied if his request for treatment is answered rapidly with quality services. We start the description of the mathematical model of the treatment tasks scheduling problem by introducing the necessary sets:

Let R be the set of material resources to be allocated.

R= $\{r_1, r_{2, \ldots,} r_u\}$, with u the total number of these resources.

Let P be the set of patients.

P= $\{P_1, P_2, \ldots, P_h\}$, with h the total number of patients.

Let K be the set of skills that can characterize each MSA.

K= $\{K_1, K_2, \ldots, K_f\}$, where f is the total number of skills that medical staff can have.

Let D be a boolean variable for MSA availability. If it is free, D=true, otherwise D=false.

Let A be the set of MSAs Ag_x, where x is his position in the PED. Each MSA is characterized by Skills and availability, Ag_x=f (K, D).

Let T be the set of treatment tasks to be executed. T= $\{t_1, t_2, \ldots, t_L\}$, with L the total number of tasks to be scheduled. A treatment task t_j€T consists in the allocation of a number {numberAllocated} of medical resources (resourceID) to treat a specific patient (patientID) under some constraints (the deadline for patients treatment: d_i and the treatment time p_i).

A task is formalized as follows:

Ti: <patientID; MedicalStaffID; materialResourceID; amount; $d_{i;}$ p_i>

D. *Performance indicators evaluation*

We choose to assign to patients treatment in the PED a cost that represents the total treatment cost for satisfying the patients. It is composed of fixed performance indicators. To formulate these indicators, we need some sets of binary variables.

Let m be a member of Medical Staff A.

Let i be the index of treatment operation.

Let j be the index of patient.

$X_{m,k,i,j}$ = affectation of Medical Staff having the skill k for treatment task i of patient j.

$$X_{m,k,i,j} = \begin{cases} 1 \text{ if Medical Staff is used} \\ 0 \text{ otherwise} \end{cases}$$

The variable representing the use of material can be as:

$Y_{r,i,j}$ = use of material resource r for treatment task i of patient j.

$$Y_{r,i,j} = \begin{cases} 1 \text{ if Medical material resource is used} \\ 0 \text{ otherwise} \end{cases}$$

The performance indicators can then be defined as follows:

C^{MStaff}= Medical staff cost for patients treatment,

$C^{MatResources}$=Material resources cost allocation,

$C^{Waiting\ time}$=Penalty of delay in treatment.

Let C_i be the cost of one working hour of one of the Medical Staff m.

$$C^{MStaff} = \sum_{mi \in A} C_{m_i} * X_{m,k,i,j}$$

Let C_p be the cost of delay in treatment per minute for patient r.

$$C^{delay} = \sum_{p \in P} C_p * D_p$$

With D_p the total minutes of delay.

Let C_i be the cost of the material resource r_i.

$$C^{MatResources} = \sum_{ri \in R} C_i$$

Once each cost is calculated, a comparison with reference costs will be done: C_{Ref}^{MStaff}, C_{Ref}^{delay} and $C_{Ref}^{MatResources}$.

V. Simulation

To better explain our approach to resolution, we propose the following illustrative example:

Representing an initial scheduling (Figure 5) consists of 9 care operations assigned to two medical staff "nurse" and "doctor" able to execute them. Medical care procedures can be done at the same time (for example, in case of Concussion, a doctor makes a diagnosis while a nurse is doing a carefully Neurological Exam for the same patient). Therefore, the operation can be performed carefully by mobilizing members of the Medical Staff at the same time and with the same duration or with varying execution times according to the skills required for the treatment realization.

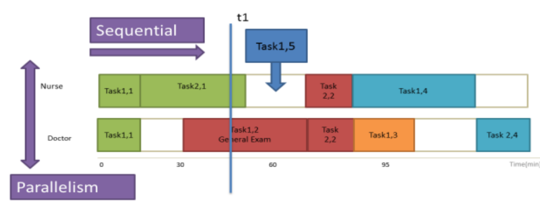

Figure 5: Tasks scheduling

At t=t_1, a new patient arrives. A doctor is needed for his treatment. Thus, the doctor (MSA) leaves the box where patient 1 is being treated to go to another box to treat patient 5. An operation may also be accomplished or interrupted by an emergency.

A. JADE PLATFORM

We are developing our system with JADE (Java Agent DEvelopment framework) platform [12]. JADE simplifies the implementation of MAS through a middleware that complies with the FIPA (Foundation for Intelligent Physical Agents) specifications and provides a set of graphical tools supporting the debugging and deployment phases. JADE system supports coordination between several agents FIPA and provides a standard implementation of the communication language FIPA-ACL, which facilitates the communication between agents which complies with FIPA specifications [13]. JADE is written in java language, supports mobility, evolves rapidly and until there, it is the only existent multi-agent platform which tolerates web services integration [14]. In this paper, we used a JADE graphical tool which sniffs message exchange between agents. This tool is useful to debug a conversation between agents.

Figure 6 shows the evolution of message exchange between the different agents through the "sniffer" tool useful for debugging.

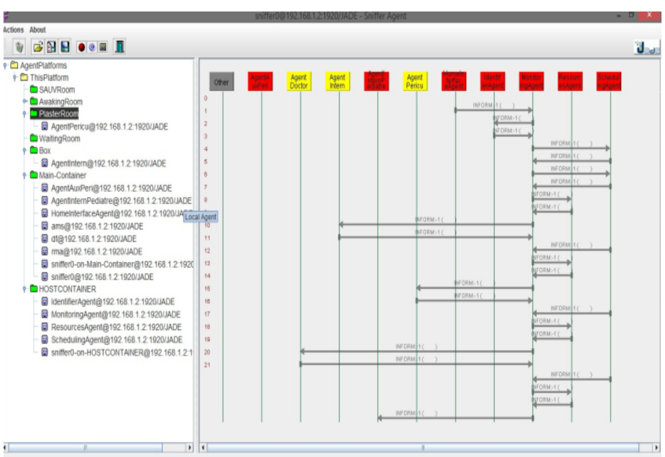

Figure 6: Communication between agents

B. Scheduling system implementation

The final assignment solution of MSAs to tasks is deduced from diagnosis generated by IA and our list algorithm results. On the Sniffer graphic tool (see Figure 6), "SAUVROOM", "AwakingROOM", "PlasterRoom", "waitingRoom", "Box" represent available PED department containers, where MSAs can move in order to treat patients according to the adopted contract model.

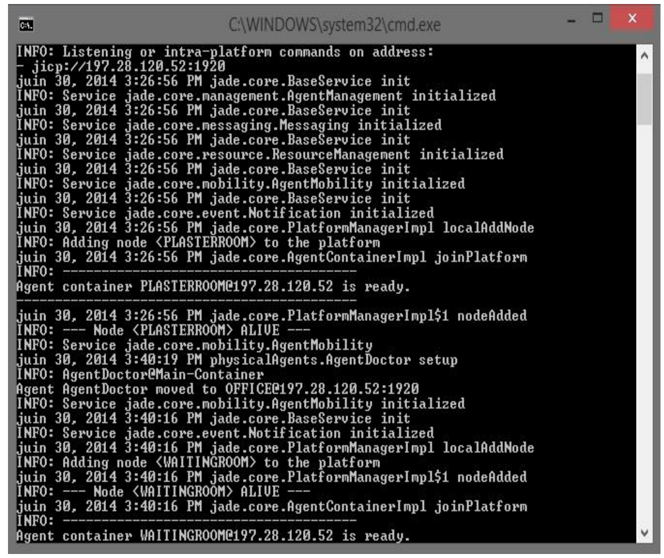

Figure 7: Agent migration

VI. CONCLUSION

In this paper, we have proposed an intelligent system for the care of patients in the PED based on framework for dynamic scheduling. The proposed solution introduces the possibility to satisfy the needs of patients while minimizing the costs related to delays in treatment, human and material resources allocation and waiting time of patients. This application proves the efficacy of the approaches proposed by the multi-agent community to attain some of our objectives. In a future work, we aim to detail the behavior of MSAs.

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