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Home Health Care: A Multi-Agent System Based Approach to Appointment Scheduling

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***Abstract-* This paper examines the application of sweep-coverage mechanism of multi-agent systems (MAS) in a home healthcare setting. The MAS is a powerful tool which acts in an autonomous and intelligent approach in order to tackle the issues of large size and complexity of systems. Although the MAS are vastly utilized in multiple healthcare domains, in this research for the first time the sweep-coverage control of multi agent system is investigated for a specific area where patients receive treatments from a hospital. The therapists as agents travel to the patients' location and complete the treatment process collaboratively. The problem of scheduling the therapists such that they are able to achieve the patients' coverage is really challenging when it is important to use a resolute number of therapists. We adopted a heuristic algorithm from MAS which aims at determining the number of therapists who work in the treatment process while covering all the patients as the points of interests in a defined time period. The cooperation among the agents provides efficiency in the overall process of care and thereby resulting in a schedule for treatment process. The therapists should be scheduled to visit the patients based on an optimized and efficient timetable to ensure coordination of the execution of home healthcare activities. The long term purpose of the study is to generate a treatment schedule to ensure all of the patients are covered for treatment process within the predefined area using minimum resources.**

***Index Terms-* home healthcare, sweep coverage, multi agent system, heuristic algorithms, treatment schedule**

I. INTRODUCTION

Healthcare services are very important issues in all societies because they directly influence the quality of citizens' lives. When the population becomes older, the society is in need of more healthcare professionals. The US Census Bureau projects that by 2030 there will be more than 70 million Americans aged 65 and older, more than twice the number in 1995. [1] Home healthcare is providing the professional services for patients who are staying at their residence. A wide range of services such as physical therapy, medical treatment, and general assistance to the patient are available as home healthcare services. Many home healthcare organizations exist in the United States. This number will continue increasing at an accelerated rate leading to greater competition between providers [2]. Improving the administrative and assistance processes in home healthcare through Computerization leads to optimizing the treatment resources and care procedures. To remain profitable, organizations must find new ways to better manage their assets and resources.

Multiple intelligent approaches are applied in order to tackle the problems of modelling, design and development of complex healthcare systems [3], [4], [5]. A leading area of research in artificial intelligence is multi agent system (MAS) which has been widely studied for healthcare domain applications [6], [7], [8]. A multi-agent system is defined as a collection of autonomous agents that communicate together to coordinate their activities in order to solve a problem that could not be tackled by any agent individually [9]. In healthcare systems knowledge is distributed in different locations; however several entities keeping their autonomous behaviour, they have to link their problem-solving abilities to be able to solve a complex problem in order to reach their purposes in such a distributed environment.

Extensive work has been done for different coverage problems of agents and sensor networks, even though the appointment scheduling of home healthcare services using coverage control of multi agent systems has not been studied before. A critical aspect of this effort is the number of agents which in this case are therapists who perform the care and treatment process of all the patients. The objective of the models is to find the minimum number of therapists who work in the treatment process while covering all the patients as the points of interests in a defined time period. The physicians should be scheduled to visit the patients based on an optimized and efficient timetable to ensure of coordinating the execution of healthcare activities. The application of agent-based paradigm proved to work best in planning applications.

Figure 1 shows a typical home healthcare system. The hospital is the original location where all the therapists start their treatment journey to patients' homes. The two red lines show how traveling starts and finishes at the hospital location, and the black arrows show the movement from one home to another to cover all of the patients who requested a category of home care service. There are multiple ways to travel from one home to another which differ in distance and time needed to complete the task. In this study we proposed a heuristic algorithm which aims at minimizing the number of therapists in the treatment process while covering all the patients at the points of interest in a defined time period. The therapists should be scheduled to visit the patients based on an optimized and efficient timetable to ensure coordination of the execution of home healthcare activities.

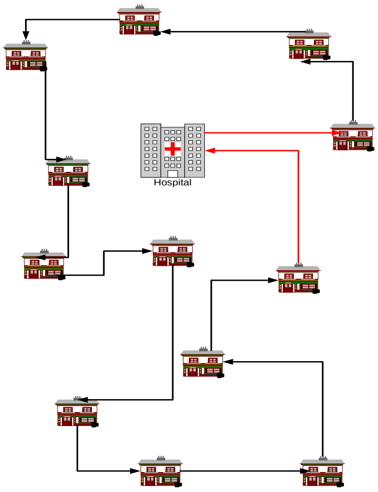

Figure 1: Sample home healthcare system

Since all the homes should be visited during a determined time period, this problem resembles is a sweep coverage using minimum mobile sensors. In this paper the sweep coverage mechanism is discussed to address the issue that exists in the home healthcare scheduling. We study the sweep coverage scenario in which we only need to monitor certain points of interests (homes) periodically, and utilize a small number of agents (therapists) to achieve sweep coverage among a much larger number of POI [10]. As a result, how to apply the algorithm to schedule the agents to achieve sweep coverage efficiently is our target. The cooperation among the agents provides efficiency in the overall process of care by applying the minimum number of therapists as agents and thereby resulting in an efficient schedule for treatment process. The contribution of this paper is that we offered a model of home healthcare and solved it with previously defined heuristics which demonstrates a new application of sweep coverage in the healthcare setting. Then we evaluate and discuss further the challenges and proper solutions for the mentioned model.

II. RELATED WORK

The study by Moreno [12] argues why MAS are appropriate tools for many healthcare problems. Some Characteristics such as communication, collaboration, cooperation and coordination have been discussed through multiple examples [16] , [17]. Then some various fields of healthcare where MAS are used such as patient scheduling, organ transplant management, community care, information access, decision and systems, internal hospital tasks are discussed by means of examples. In the comprehensive study by Isern et al. [8] multiple areas of application of agent-based systems in healthcare are presented. They divided these areas into five different parts including: medical data management, decision support systems, planning and resource allocation, remote care/telemedicine and pervasive care, and composite systems. Our research falls into the category of planning and resource allocation which is argued to be the area which agents' characteristics fit the best. In order to tackle the planning problems using agent technology the best way is to associate an agent to each involved entity so it can imitate its behaviour. Therefore, highly complex problems can be divided into individual pieces making them easier to implement and behaviours appear naturally.

In studies related to artificial intelligent application in home healthcare studies there have been many modeling and design problems. To enlighten this discussion we here present some of the previously done studies in the domain. A popular example of multi agent systems are wireless sensor networks (WSN) which has a wide range of application in widespread areas. An important research problems in MAS design is to provide coverage to the monitoring area. A special type of coverage is sweep coverage in which a set of Points of Interests (POIs) in the monitoring area are periodically monitored instead of continuously monitored. A centralized algorithm was introduced by Li et al [13] for this type of coverage problem. In a study by Du et al [10] two heuristic algorithms developed for sweep coverage of agents which proved to excel those algorithms proposed by Li et al. [13]

III. METHODOLOGY

In this section assumptions are presented, the collaborating agents and the environment of the model is defined. A model of home healthcare is offered and solved with previously defined heuristics. This model and adopted solving method demonstrates a new application of sweep coverage in the healthcare setting.

3.1 Problem Statement

In sweep coverage a set of point of interests (POIs) but not all points in the monitoring area are periodically monitored instead of continuously monitored. Here we aim at scanning all the patients (POIs). To achieve sweep coverage it is not necessary to deploy many therapists-agents to provide a continuous monitoring, instead a group of agents are deployed in order to travel and scan the POIs once every sweep period. [10]

In an ideal state the sweep period of the patients are infinite and the therapists are available all the time. As a result it is possible to cover the area by applying only one therapist. In a real situation the therapists are available only in some specified hours of each day in a defined treatment time frame. Also the sweep period of the patients is limited which means they should be covered for care process in their requested time. The problem arises when we have to use multiple therapists to achieve the sweep coverage task. Therefore the question is how many therapists are sufficient for the care process of a set of given patients in their place of residence?

3.2 Agent Definition

In our proposed model the definition and purpose of the agents are summarized in Table 1. Three distinguished type of agents work together to fully reach the goal of the system which is the efficient treatment of all the patients at their place of residence. First of all, the patient-agent makes an appointment for a home healthcare by contacting the hospital. Then the hospital-agent collects the data from those patients who requested an appointment, accordingly the locations of all the patients are recorded. Also, it has the information of all the therapist-agents who are assigned to the home healthcare section of the hospital. Then the hospital-agent generates the plan for visiting and treatment of all the patient agents.

There are multiple therapist-agents which constitute a multi-agent system. The hospital is the origin of the therapists which means they start any treatment journey from hospital. The therapist-agent is responsible for informing the hospital about his availability and then receives the care schedule from the hospital-agent. After finishing any of the treatments the therapist-agent sends a visiting report of the patients to the hospital-agent.

Table 1: Agents definitions and functions

Patient agent: Represents the patient which is treated and cared.	- Makes an appointment - Records the progress and health condition of the patient - Each of these agents stores some static data related to the user such as: National healthcare number, Name, Address, Access information . . .
Therapist agent: Represents each of the therapists, responsible for delivering the treatment	- Finish the care and treatment process based on the schedule - Informs the hospital agent about his time and availability - Reports the care process to the hospital agent - Collaborate among themselves to be informed about the next target patient
Hospital agent:	- Gathers the information about the patients and their desired time of treatment - Stores the information of all the therapist agents who are assigned to the home healthcare section of the hospital. - Generates the plan for visiting and treatment of all the patient agents

3.3 Problem Environment and Assumptions

As we mentioned before the hospital-agent is responsible for preparing the treatment schedule. In this section we explain how our system is defined and simulated to generate this treatment plan for healthcare.

When the hospital agent collects the data from those patients who requested for a home healthcare service, the location of all the agents are recorded. As a result the agent defines the area of the sweep coverage problem as a rectangular which includes all the patients who are points of interest for each sweep period. The next step is to define the area of the coverage problem by the hospital agent. The target zone is specified as a rectangular shape area which is planned to be covered at full usage of the system that includes all the patient agents.

Therapist-agent: The therapists have the same skill and expertise and offer the service to all the patients. At each point of time they know their location. The position and sweep time interval of all POIs are pre-known by each therapist. Enough therapists are available. All therapists travel with the same speed and they are available for 6 consecutive hours for each treatment period which is a 24 hours day. All therapist-agents move along disjoint path, which means each therapist agents covers a set of the POIs (patients). The origin of the therapist who travels first is the hospital. The subsequent therapist-agents are connected to the previous agent, so when one agent finishes treatment process he collaborates with the rest of the therapists to make them aware of the next POI to be visited.

Patient-agent (POI): There is no priority or emergency case among the patients. They all been treated based on the schedule which they have been informed in advance. All the patients have a unique ID and a fixed position. The sweep coverage of a patient in a specific time period is when a therapist-agent is at the same exact location as the patient. The treatment time is a uniform distribution with an average of 30 minutes for each patient.

Given the sweep coverage model with a set of POIs and the requirement of their sweep periods, the problem is to determine the minimum number of therapists for sweep coverage of the environment including patients. To start the modelling we assume we have “n” therapists then we try to find the minimum number of therapist-agents (n) to finish the treatment process. Here we explain some details about the parameters in the code and how it works. Firstly, the code defines the number of patients as parameter p. The “p” is flexible and can be changed based on the user preference, meaning that it is changeable based on the number of the patients who called to make an appointment. For shaping the rectangular area where all the points of interests (patients-homes) are located, parameters “x” and “y” were defined considering the area which determined to be covered by the hospital agent. The treatment time is defined as “time” which is a uniform distribution with an average of 30 minutes.

Starting from the hospital which is point x0 = [0,0] , the first available therapist drives to the closest patients home called corner POI, the next patient to be treated is the one who has the least distance to the current location of the therapist agent. Moreover, all therapist-agents can announce their location by using some GPS external devices. The distance travelled among the points of interests is used to calculate the required time to travel and cover all the POIs. It is then sums up with the treatment time of all the patients to prepare the schedule for treatment. Based on the assumption about the availability of therapists, each of them can work for 6 consecutive hours in the system. So when a therapist finishes the treatment and time is up then notifies the hospital-agent about the current situation so the next therapist continues the process at the next POI which is nearest where the previous therapist stopped.

3.4 Step by Step Algorithm

The inputs of the algorithm are:

- Number of patients: the set of POIs. P = {z1, z2, . . ., zp} points randomly distributed in a two-dimensional plane.
- Hospital location: The hospital is assumed to be located in the origin point.
- Environment: It is the area where the patients are scattered, in the algorithm this area is rectangular and it is defined based on the location of the patients
- Treatment time: It can be a uniform distribution if there is no priority for treatment; on the other hand we further applied exponential distribution for acute cases.
- Patients’ location (X, Y coordinates): The patients are located randomly in the defined environment.

The algorithm follows the mentioned steps below:

1. Define the hospital location on origin and distribute the set of POIs in desired environment and put the POIs in set M
2. Enter the treatment time of the patient
3. Define matrix A which will consist of all the POIs that has been covered

4. Calculate the distances between hospital and all the points in M as set D={ dij }
5. Find the minimum dij and put its corresponding point in A , this is called corner POI which is the POI that has the smallest dij from the origin
6. While M=0 repeat the following loop:
   - Calculate the distances from recently added point in A and all the remaining points in M and put them in D={ dij }
   - Choose the minimum dij and the corresponding point
   - Add result step (b) to the matrix A
   - Omit the candidate POI from set M

7. Calculate overall distance travelled, treatment time, graphical plot of patient location
8. Calculate m=number of therapists

The outputs of the algorithm are:

- Patients location graphical plot
- Distance (among patients): when the algorithm moves from one patient to the nest it calculates the distance traveled among all the patients
- Scan path: shows the scan path of one therapist who is covering all the patients for treatment process
- Number of therapists: time needed for treatment is added to the required time to travel the distance among patients is being used to calculate the number of therapists.

Figure 3 shows the applied algorithm as a flowchart. The corresponding code was written in Mat lab.

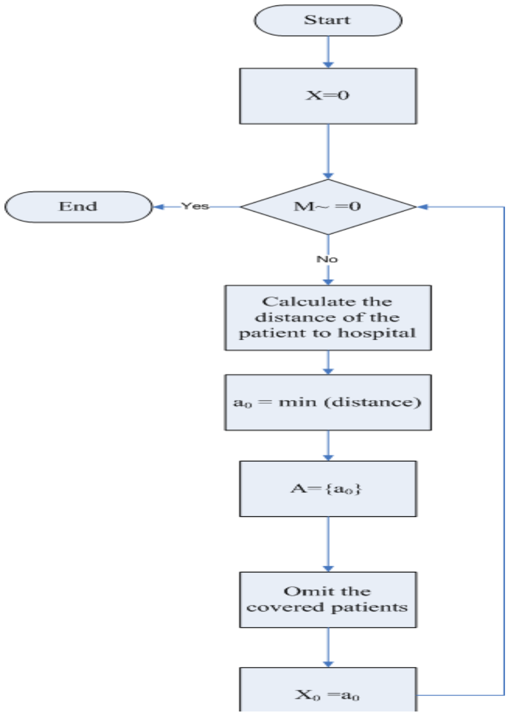

Figure 3: Flowchart for the algorithm of determining the number of therapists

IV. DISCUSSION

In this section we describe how the algorithm works and show some sample runs to validate the efficiency of the algorithm. Then we explain the strong aspects and weakness of the model. To show the overall system, we simulated a two-dimensional plane of (100*70), where all the POIs are deployed shown in figure 4. We assume that patients (POIs) are randomly distributed in this plane.

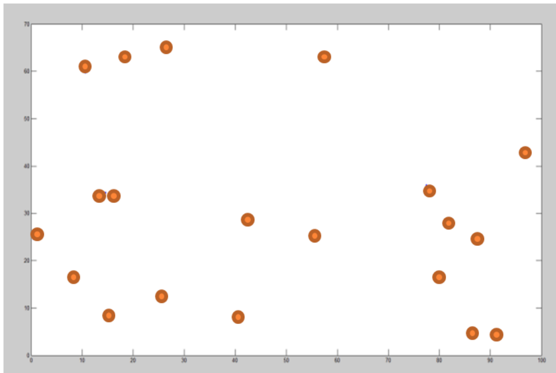

Figure 4: (100*70) plane where POIs are spread

In figure 5 a sample run of the system is shown. The hospital is located on the origin point (0,0). The first therapist in duty starts his journey from hospital and travels to the patient's home who is closer to the hospital and the algorithm proceeds based on the next POI which is closer to the location of the earliest POI that is covered. Since any therapist is available for six hours, at the end of the duty time the next available therapist travels to the next patient who needs to be treated until all POIs are covered or the therapist runs out of time afterwards a new agent enters the treatment process. The traveling time and treatment time sum up to obtain the sweep coverage time of the system. Then this time is divided to the availability time of the therapists to calculate the number of the therapist needed for the entire process of care.

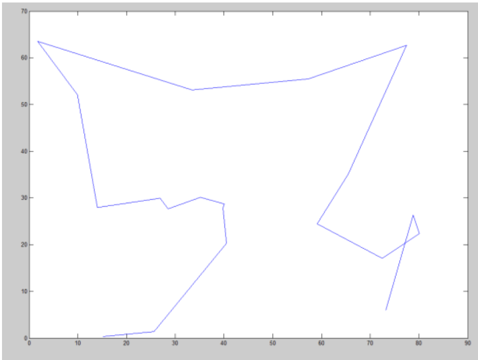

Figure 5: Respective travelled points of table 2

The points in the first column and then the second column respectively show the patients' X and Y coordinates which have been visited.

Table 2: Patients' location for a sample run

X and Y coordinates	X and Y coordinates
15.1912 0.3485	1.8134 63.5625
25.6042 1.3278	33.4291 53.0977
40.5087 20.2434	57.3020 55.4393
39.8080 27.8591	77.4646 62.6700
40.0779 28.7276	65.4390 35.0199
35.1252 30.1754	59.1447 24.4463
28.4893 27.6262	72.4810 17.0597
26.9077 29.9534	80.0483 22.3871
13.9865 27.9145	78.8027 26.3660
9.9571 52.1206	73.1679 5.9536

Figure 5 illustrates how all the patients are covered when four therapist agents collaborated to finish the job. The points covered respectively based on nearest distance.

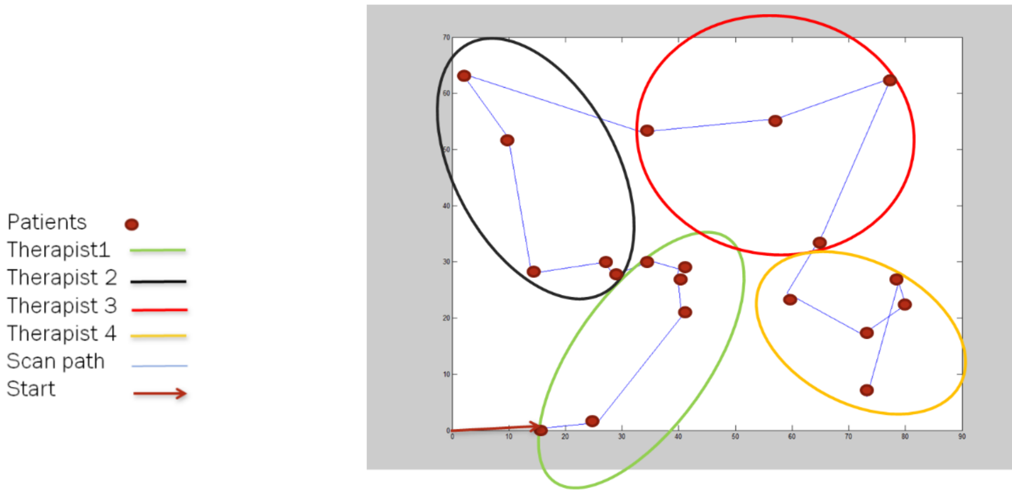

Figure 1: Covered points of interests

The blue line shows the connected scan path of all the therapists. The green contour contains the points of interest which has been covered by the first therapist-agent. The black, red and orange contours represent the 2nd, 3rd and 4th therapists respectively. In this example, the optimum schedule resulted in the 1st, 2nd, 3rd, and 4th therapists respectively providing treatment services to 5, 4, 4 and 7 patients. Also included in Figure 5 the therapists' movements from POI-1 to POI-20 (patients 1 to patients 20) while the overall coverage being achieved. Table 3 demonstrates the time needed to cover all the patents based on the availability of therapists. Travel time is for going from one patient location to the other. The idle time is calculated by subtracting the time needed from six hours availability of each therapist.

Table 3: Therapist schedule for completing the treatment process

Therapist	Therapist 1	Therapist 2	Therapist 3	Therapist 4
Number of covered (POIs)	6	5	4	5
Time needed	5h, 50min	5h, 25min	6h	5h, 35
Idle time	10 min	35 min	0 min	25 min
Travel time	2h, 50min	2h, 55min	4h	3h, 5min
Treatment time	3h	2h, 30min	2h	2h, 30min

One of the positive aspects of modelling in this way is that the code is flexible, meaning that we can change the number of the patient based on the demand of the home healthcare service. Also the environment can be defined regarding the location of all the patients who are the points of interest of the problem. The answer will vary in accordance with the input. The output of the problem is the minimum number of the required therapist for the coverage of all the patients. In Figure 6 the input, process, and output of this home healthcare service. The code execution results in determining the number of therapist-agent to cover the area, so the hospital agent plans and schedules the required therapists for the next day based on their availability. As a result each therapist has a scan path and they cover all the patients. The program has been run for 100 times and the average output for 100 repetitions are mentioned in table 4.

Table 4: average number of required therapists

Number of run	10	100	1000
Average therapists needed	3.57	3.49	3.55

These averages all round up to four because of calculating the number of the people required to finish a task. As a result all the POIs are covered by calling four therapists.

Here the result of the algorithm when the number of patients are varied is illustrated. Table 5 shows the number of required therapist for each given set of patients and the distance travelled for each case. Figure 6 shows a graph which represents the increasing minimum number of required therapists when the number of patients grows from 10 to 100.

Table 5: Number of therapists required and distance travelled for the normal case

Number of patients	Number of therapists	Distance	Real number of therapists needed
10	2.3254	265.9109	3
20	3.7396	369.7120	4
30	5.4700	489.5327	6
40	6.5840	501.9704	7
50	6.7118	509.1463	7
60	7.5844	522.4528	8
70	10.0648	695.3046	11
80	10.8002	753.8298	11
90	10.4558	699.4790	11
100	13.6501	811.2785	14

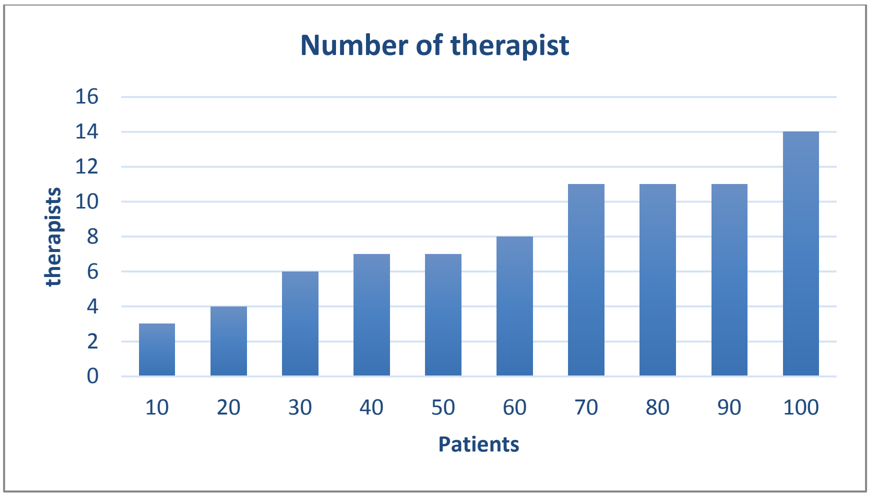

Figure 6: Number of therapists needed for normal case

Another aspect of the study is considering the acute cases among patients. Regarding the programing issue, the treatment time of the patients is considered an exponential distribution with the average of 60 minute for treating each patient. Table 7 shows the number of required therapist for each given set of patients and the distance travelled for each case. Figure 7 shows a graph which represents the increasing minimum number of required therapists when the number of patients grows from 10 to 100.

Table 6: Number of therapists required and distance travelled for the acute cases

Number of patients	Number of therapists	Distance	Real number of therapists needed
10	2.6191	229.2929	3
20	4.2236	330.5954	5
30	8.3905	461.4747	9
40	8.4527	419.8539	9
50	11.4726	578.6616	12
60	11.5634	600.0238	12
70	15.9130	614.6368	16
80	16.6807	633.3865	17
90	15.0860	750.5336	16
100	22.7313	758.7761	23

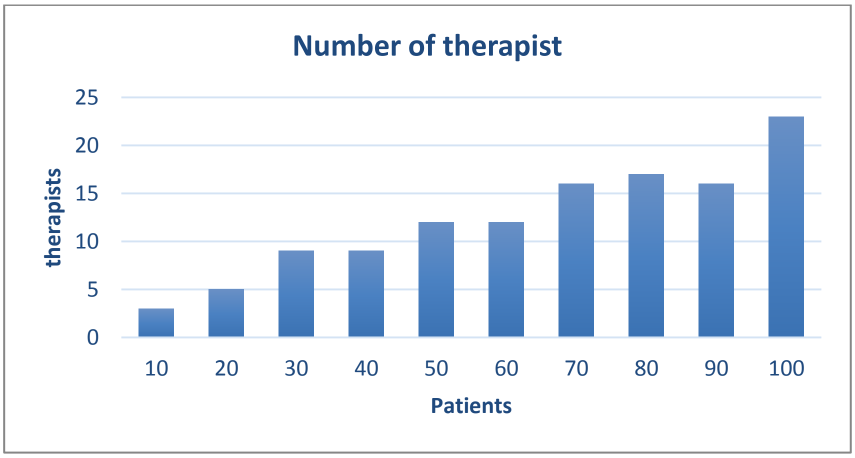

Figure 7: Number of therapists needed for acute cases

V. CONCLUSION AND FUTURE WORK

In this paper we applied the coverage scenario in which we only need to monitor certain points of interests periodically, and utilize a small number of agents (therapists, resources) to achieve sweep coverage among a much larger number of POIs (patients). The cooperation among the agents not only provides efficiency in the overall process of care by applying the minimum number of therapists-agent but also leads to an efficient schedule for the treatment process. We adopted a heuristic algorithm from a previous work done in the area of agent technology and applied it for scheduling therapists in our defined model of home healthcare with the aim of covering all the patients while using the minimum required number of therapists. A real application of this model can be a decision support system at a hospital to schedule the therapists based on their availabilities and the appointments that have been made in advance from patients who are staying at their places of resident. The advantage of the model is that it can be applied for any given number of patients who scattered in the target area for receiving treatments. Consequently, the model is flexible and can facilitate the delivery of the care to patients. Scheduling of therapist in this manner results in reducing the waste time. The collaboration between therapists about the current status of the system expedites the process of care while ensuring all the patients are covered based on the predefined schedule.

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