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Multi-Agent System Based Framework for Efficient Laboratory and Patient Scheduling Services in Health Care Setup

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***Abstract*—**Multi-Agent System (MAS*)* is a system consists of multiple interacting intelligent agents within an environment. Health care services can be efficient, if early diagnosis and timely cure of disease takes place. This paper explores how health care services can be efficiently provided by deploying multi-agent systems for the cooperative functioning of patients, medical practitioners, surgeons, nursing staff, paramedical staff and other allied health care service providers.In this research work, multi-agent based Laboratory Management System (LMS) is proposed with an aim to delegate day by day job done by technical or nontechnical staff to the proposed agents. A multi-agent based Appointments & Scheduling System (ASS) is also proposed.

***Keywords*—**Multi-agent system; health care services; patient appointments and scheduling; laboratory module; hospital information system.

I. INTRODUCTION

The health care system in general is characterize by being a multi-actor, extensively scattered and exceptionally complex system [1]. MAS offer an effective way of providing solution for such systems [2], [3]. The patient related information is widely distributed in different units within a hospital. The various agents of the multi-agent systems may be running in different computers located either in hospital or at the residence of a patient with different information required to provide the efficient healthcare services [4]. Integrated Multi-agent System (IMAS) is a system that provides real time monitoring, diabetic health care management and decision support to the diabetic children [5]. The collaboration situation between different stakeholders (Hospital Nurses, School Nurses and Parents) is improved by agent-based services. Geriatric Ambient Intelligence (GerAmI) is a multi-agent based intelligent supervision system that provides support to elderly and Alzheimer's patients in all aspects of daily life, predicting potential hazardous situations and delivering physical and cognitive support. The system combines simple tasks like the verification of the location of patients with complex tasks like the creation and management of a everyday scheduling for a nurse [6]. In [7], an agent based system is developed to help a patient in carrying out a search of the hospitals and healthcare facilities. It too enables putting in place an appointment with a suitable consultant, once the selection course is finished.

Hospital Information System (HIS) [8] is an enterprise wide tool that is made up of a number of modules to provide clinical services (Registration, Out Patient Department, In Patient Department, Emergency, Laboratory, Central Sterile Supply Department, Blood Bank, Diet & Kitchen, Patient Billing, Duty Roster and Appointment & Scheduling), Support Services (General Patient Enquiry, Transport, Security, Sanitation, Laundry) and Back Office Services (Accounts, Hospital Equipment Maintenance & Infrastructure Maintenance, Procurement & Online Inventory, Administration). These modules help to organize the data in a manner that will allow the seamless flow of information in the hospital environment. Laboratory Module in a HIS captures information related to various investigations required for the routine functioning of the hospital. It allows for flexibility in the interfacing of laboratory equipment and the ease of accessing information from a number of different database types. Appointments & Scheduling Module in a HIS covers the fixation of patient appointments and scheduling of each department's activity.

In this paper, the proposed Laboratory Management System (LMS) will allow medical practitioners to focus their concentration on investigation of samples, investigation outcome understanding and medical assessment making. It will also allow the doctors/patients to view the investigation outcome transmitted by agents everywhere and anytime. A multi-agent based Appointments & Scheduling System (ASS) is also proposed to fix the appointments and scheduling of resources in any health application.

II. LABORATORY MANAGEMENT SYSTEM (LMS)

Each hospital labs receives each day number of request through samples; investigates the samples, then delivers final outcomes to the actors (consultants, hospital departments etc.). The process of transmission of investigation outcome depends on their necessity level. Besides the lab apparatus for carrying out medical investigation, the personnel of the Hospital Laboratory are supported in their day by day tasks by the Laboratory Software (LS), combined with a traditional telephone messaging system.

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A. *Major Challenges in Present System*

Hospital Information System (HIS) raises a number of issues such as:

- Despite the fact the most important part of outcome are transferred through auto analyzers and LS, the quality of services provided by HIS depends to a more or less extent on human factors, e.g., any mistake of a lab technologist in transferring investigation outcomes to a consultant may cause affected consequences on patients.
- HIS doesn't allow the requesters to know when results become available.
- The conversation held on the phones cannot be logged automatically in HIS for monitoring and tracing purposes.
- The doctors who uses HIS spends a lot of time in searching, retrieving, consulting and interchanging the investigation outcomes.
- To establish a successful communication on phone, two communicators must be present, therefore, time is wasted if either one cannot reach the other when needed.
- The time consumed while using the HIS in many cases, consultants and laboratory technician have very less time for their real clinical activities.

B. *Proposed Solution with Agents*

The proposed solution gives consistent jobs done by human agents to software agents. In theproposed solution, each actor is assigned a personalized software agent who acts as his personal assistant. The assistant receive a list of things to do from its owner, performs the assigned jobs in close co-operation with other software agents, and delivers the final outcome to the desired requester. The software agent solution will offer the following significant advantages over LS:

- The features and functionalities of LS multisite are maintained, preserving the investment in this old laboratory software.
- In the proposed agent-based module LMS, the allocation of monotonous jobs from human actor to software agents will allow human actors to focus their attention on analysis of sample, investigation outcome interpretation, medical decision making, and so forth.
- The LMS united with portable devices (PDAs, mobile phones, smart phones, pager etc.) will allows the actors to view the investigation outcomes transmitted by personal assistants anywhere and anytime.
- All events and actions are systematically logged and centralized to support auditing of the system. Traceability and exception investigation, for example, to answer a patient's grievance will also improve.

The proposed LMS has four agent categories (Integration Agents, Alarm Manager Agents, Doctor Agents andLab Personnel Agents). The work description of these agents is illustrated in table 1.

The information flows between various agents of the Laboratory Management System (LMS) and their arrangement is shown in figure 1.

Table 1. Agents and their roles in laboratory management system.

Agent Name	Agent Job
Doctor Agent	• Gets information about the investigation outcome availability from the lab personnel agents. • Gets alerts of unread investigation outcome from the alarm manager agent. • Provide information to the consultant that investigation outcome are accessible. • Receives investigation outcome data from the integration agent. • Shows investigation outcome data to the concerned consultant. • Provide information to the alarm manager agent about the read/unread status of the investigation outcome sent to the consultant. • It also give information to the Integration agent before and after every action.
Lab Personnel Agent	• Inform to the alarm manager agent and doctor agent regarding the availability of investigation outcomes. • Receives alerts from the alarm manager agent signaling the irregular unread status of an investigation outcome. • Recognizes the alarm manager agent that the lab personnel read the alert sent to him. • Give Information to the Integration agent before and after each action.
Alarm Manager Agent	• Alerts the lab agent as soon as the unusual unread status of a given investigation outcome is detected. • Get investigation outcome from the lab personnel agent. • Get from the Doctor agent the status "investigation outcome have been read by Doctor". Receives from the lab personnel agent the status "alert message has been recognized by the lab personnel agent." • Informs the Integration agent before and after each action.
Integration Agent	• Retrieves investigation outcome from HIS, based on the query issued by the Doctor agent or the lab agent. • Delivers extracted investigation outcome to the requester agent. • Informs the Integration agent before and after eachdeed. • Log the actual start/end notifications with their date and time.

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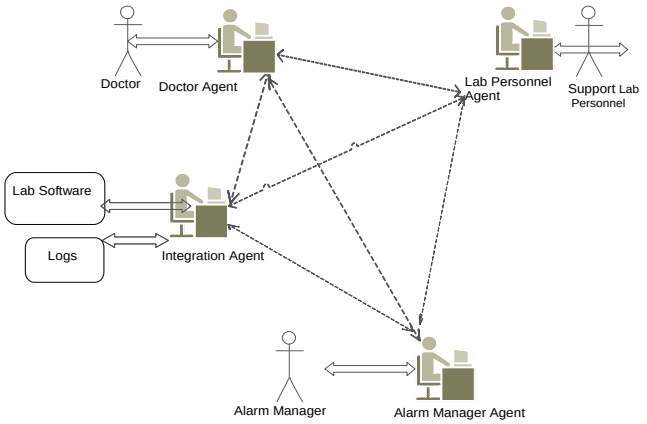

Fig. 1. Interaction between agents in proposed approach.

C. *Real Scenario Implementation with Proposed Solution*

A case study is presented to explain the real situation, and to discoverdiverse practical aspects of the proposed agent based solution. The following nomenclature is used for agents in this case study:

- InAgent is the Integration Agent,
- am Agent is the Alarm Manager Agent,
- dAgent are the Doctor Agents,
- LpAgent are the lab Personnel Agents

Suppose there are three samples sno-001, sno-002 and sno-003 in order to imitate the three investigation outcome which is then saved into the database by the lab analyzers. Beside this, the following actors will play diverse roles in this situation:

- A is a Doctor in the HIS and is assigned the ID 5.
- B is a laboratory technologist in Hospital Laboratory and is working on the samples; sno-001, sno-002, and sno-003, ordered by A.

The roles of different agents, their interactions in the proposed solution for this scenario are elaborated as under:

Notification of Investigation Outcomes Availability

- When B finishes the analysis of all three samples then their investigation outcomes will be recorded into the database as per their precedence of the samples and their level of criticality. (The precedence of an investigation is set by its requester and the level of criticality depends on its result and is set by the lab technologist.)
- At conclusion of the sno-001 investigation, if B observes that the investigation outcome are noncritical then in order to notify the availability of the investigation outcome to A (requester ID = 5), B clicks the "notify result" action button to direct his LpAgent to announce the availability of investigation outcome to the requester. If outcomes are critical then B will inform about this manually / telephonically to A.
- B treats the other outcomes in the similar way.
- B's LpAgent sends the announcements of the outcome to A's dAgent.
- It also sends these announcements to amAgent which saved it and starts to supervise closely the read/unread status of the new investigation outcome.

Acknowledgments of Notification Delivery

- Parallel with amAgent, A's dAgent receives the announcements and refreshes the list of pending outcomes of sno-001, sno-002, sno-003 investigation outcome.
- A received the announcement of sno-001 in the listing of pending outcomes in order to foretaste the details of the investigation outcome. A's dAgent requests InAgent to get the contents of the sno-001 investigation outcome from database and displays it.
- A clicks the "verify" button to acknowledge receipt of the notified announcement of sno-001 and thus directs his dAgent to mail this acknowledgement to amAgent.
- amAgent updates the status of sno-001 as "read" and removes the sno-001 announcement from his own inner list. This stop the monitoring of sno-001 by amAgent.
- Once the message is flagged as "read," A's dAgent removes sno-001 from the list of awaiting outcomes.
- A further acknowledges the receiving of results of sno-002.

It is significant to mention that the dAgent's first announcement will be flagged as "available" during a predefined time interval for usualinvestigation outcomeand critical ones. The close monitoring of awaiting announcements by amAgent will alerts dAgent as soon as an announcement is not confirmed within the predefined time interval. dAgent will immediately flags the alert announcement as "1st reminder," then "2nd reminder," and so on in the status of announced result column.

Problem Detection and Alert

- For the sno-003, amAgent has not yet received areply communication from A's dAgent within the stipulated time interval. After three unsuccessful warnings, amAgent escalates up the managerial hierarchy by sending an alert to B's LpAgent.
- On receiving this alert, B's LpAgent display it on the announcement flag.
- B's on receiving this alert through its LpAgent requests InAgent to retrieve the investigation outcome of the sno-003.
- B's contacts A manually for providing the investigation outcome of sno-003.
- B's check to "confirm" the acknowledge receipt of the sno-003 alert and thus directs his LpAgent to send this acknowledgment to amAgent.
- amAgent updates the status of sno-003 as "read," and removes the sno-003 announcement from its own internal list resulting in the termination of monitoring of sno-003.
- Once the announcement is flagged as "read," B's LpAgent and A's dAgent remove sno-003 from their respective pending list.

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- Throughout the above-simulated scenario, each agent sends the start and stop times of every performed task along with its relevant information (date and time, involved actors, action, etc.) to InAgent.

In this proposed solution, it is even possible to change the agent behavior by modifying rules at run-time (e.g., escalating up the organizational hierarchy after two instead of three unsuccessful warnings or warning another Doctor in the same group if available instead of the lab personnel).

III. Overview of Appointments & Scheduling in a Hospital

The appointments and scheduling module in a Hospital Information System covers the fixation of patient appointments and scheduling of each department's activity [9]. Appointment fixation allots prior dates for those patients who desire to see a doctor or visit the hospital. It keeps track of available slots in various categories of appointments such as for Outdoor Patients Department (OPD), Special Clinic OPD, Lab, Minor Operation Theatre, Day Care Centre and Main Operation Theater. Number of slots can vary category wise depending on the doctor's availability, procedure time, and lab investigation time as shown in figure 2. It also covers the cancellation of existing appointments. Scheduling is done in departments to define the unit wise activity and it can be done on the daily / weekly basis.

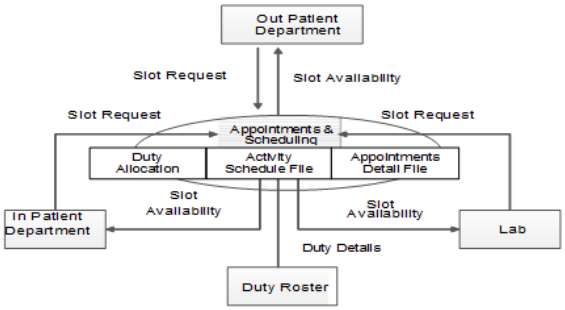

Fig. 2. Functional diagram for appointment & scheduling module.

Duty Allocation File gives the duty allocation details of all employees except for doctors. This file is accessed in the appointment process. Master Holiday File / HOSPITAL calendar gives the holiday details applicable for HOSPITAL in a calendar year. Activity Schedule File gives the activity wise scheduling details between the defined time periods. Appointments Detail File gives the details about all activities for which appointments have been given at a particular date, time and to whom.

A. Major Issues in Appointments & Scheduling Module

In hospital patient scheduling, the patients reach regularly at the hospital and the required medical treatments are frequently not completely known at the start of the treatment process. Additionally, the new outcomes during investigative examinations change the medical priority of the patients, invoke additional treatments or examinations or create other medical actions obsolete. Moreover, the durations of treatments and investigations are stochastic. Finally, complications and arrivals of emergency patients which are in urgent need for treatment result in schedule disturbances. Because the auxiliary units only have a limited view and cannot consider the complete pathway of the patients, no inter-unit process optimization is possible (i.e., the medical tasks for the patients cannot be scheduled and coordinated in an efficient manner). This causes undesired idle times as well as overtime hours for the hospital resources and extended patient stay times.

Table 2. Agents and their roles in appointment and scheduling system (ASS).

Agent	Agent Job
Patient Agent	• It handle the appointment request for the patient services such as OPD, Surgery, Procedure, Lab investigation etc. • Communicate appointment status to patients through Internet. • Interfacing with the patient appointment database and the appointment agent.
Appointment Agent	• Interface with the patient agent and main agent. • Automatic search for the earliest available appointment. • Maintaining the appointment slots activity wise. • Checking the completion of pre-requisites for the medical service before assigning the appointments. • Provide confirmed appointment information to the appointment requesters.
Main Agent	• Most critical agent that interfaces with the appointment agent and doctors schedule agent along with the hospital main database. • Interrogate appointment request against the doctor schedule in an effort to provide available appointment slots. • Creation / updation of the schedule. • Provision for overbooking as per conditions lay down by the appropriate authority. • Provision to squeeze the slots in case of overbooking.
Doctor Agent	• Online availability of the Doctor's schedule. • Interface with the appointment of doctor database and the schedule agent.
Schedule Agent	• Interfaces with the main agent and provides confirmation of the doctor schedule and confirmed appointments. • Maintaining the list of scheduled patient's appointments for doctors. • Keeping an inbuilt check to ensure that scheduled appointment falls on doctor / specific activity day. • Rescheduling the appointment if the concerned doctor is on leave.

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B. *Proposed Solution*

Presently the patients face problems to have the time of medical personnel, especially experts, for either diagnostic or more urgent operational reasons. The patients may choose to walk in and wait for the personnel to become available but they usually end up waiting for very long periods of time. The patient can, however decide to schedule an appointment, but this option does not usually work well for all parties involved i.e. the patient, the medical personnel and the hospital. The patient wishes for readily available and convenient appointment to times. When they do not find a close enough appointment time they still experience long periods of indirect waiting time (time between scheduling the appointment and that appointment becoming available). The patient also wishes to be seen either immediately or within minutes of their arrival (whether they scheduled an appointment or not). The proposed multi-agent based solution ASS consists of five agents interacting with three different databases as shown in figure 3. Table 2 illustrates the functionality of each agent deployed in the proposed solution.

In order to fix appointments in any health applications, the hospital normally employs a human agent to get the work done at the appropriate health care facility. But with the proposed solution, such a job can be done in the mobile environment by deploying agents.

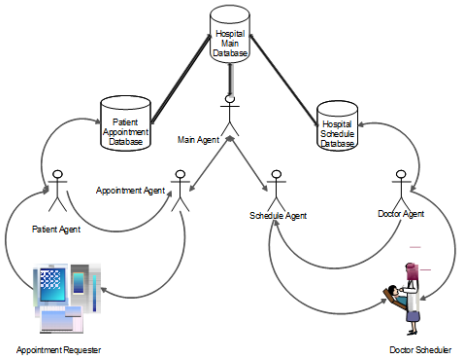

Fig. 3. Interaction between various Agents in appointment & scheduling system (ASS).

IV. Conclusion & Future work

In this paper, an intensive study has been made on Laboratory module and Appointment & Scheduling module of Hospital Information System (HIS) in order to find how the healthcare services will be made efficient with the use of Multi-Agent Systems (MAS). Two multi-agent based systems are proposed which can fulfill the functionality of these systems and also overcome the problem persisting in the present systems. Similar kind of detailed study can be carried out to propose multi-agent based solution for other areas of the health care services such as In-patient Module.

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