Towards Maturity in Multi-agent Based Remote Patient Monitoring

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***Abstract* - Multi-agent systems (MAS) simplify human life with automated functioning. This approach has also been implemented for remote patient monitoring (RPM). The objective of this paper is to find weaknesses in existing technology and to contribute to enhance the system with mature functioning. To achieve a robust system, we propose the optimized nomadic devices based RPM framework. Finally, we demonstrate the prototype system developed on our proposed framework. Our RPM system outperforms to the existing ones.**

***Keywords*–** RPM, MAS, Comparison, E-Health, Network and GPRS

1. INTRODUCTION

The MAS is able to solve real problems, examples of applications are: NASA's Deep Space 1 (DS1) mission, air traffic control system, holiday package finder, sniffer, chess master, industry supporting robots and so on. To carry out tasks, agent percepts the environment, selects appropriate actions to apply, and performs changes on the environment like robot arm movement. Communication is a very important functionality in MAS, because agents work as a team, collaborating with others, by means of message passing [1].

The remote patient monitoring (RPM) is a field where patient is monitored remotely through communication technologies (e.g. web) by the medical staff. It is important to observe status of the patient in real-time which web technology unfortunately is not seemed to fulfill. In this regard, multi-agent systems (MAS) can play an important role where agents automatically perform patient monitoring and do remedial action in emergency condition (e.g. medicine dose, precautions, alert to hospital staff etc.). The agent based RPM provides number of benefits: reduce loss of life, automated working with less human interaction, facilitate villagers and chronically ill patients, vacant beds for emergency patients and so on.

In RPM environment, agents perform different role like doctor, patient, specialist, and nurse. The agent on patient location monitors continuously health status of the patient, working on a computer or a cellular device. The patient's agent provides proactive care and notifies the patient before happening emergency condition. Upon obtaining updated information (high temperature), patient agent sends report to doctor and patient records. The doctor agent analyzes report based on historical data and may send it to specialist agent for later diagnosis. Thus, frequent visits to doctor are reduced considerably. Additionally, chronically-ill patients do not have to occupy hospital beds for long time, remaining available places for emergency patients. Consequently, RPM may provide medical services in populated villages where hospitals are not enough [2].

Currently, MAS-based RPM systems are in growing phase and require maturity in different areas (e.g. alternative to continuous GPRS connection, battery life of nomadic devices and data management in the network, etc.). Realizing this need, we have proposed a MAS-based RPM framework in this paper. We have given solution of significant problems that is a step towards maturity in this domain.

This paper targets to study RPM systems based MAS approach. We explain related work in Section 2, following, we briefly overview the RPM approach in MAS environment in Section 3. With this vision, we propose a framework in Section 4 while comparison among different approaches is given in Section 5. Then prototype system implemented on proposed concept is demonstrated in the Section 6. Finally Section 7 concludes the work and provides future directions.

2. RELATED WORK

Multi-agent paradigm has been shown to be precise in assigned tasks in sensitive environment. A detailed survey on the Multiagent RPM highlights characteristics such as reusability, flexibility, reliability, robustness, adaptability and maintainability [21]. The Multiagent based system for collaborative scenario presented in the telemedicine field [5] is applied for patient appointment, where external specialist functions are implemented for doctor appointment. The similar work is also presented in [22].

To monitor patients at home through the Internet is proposed where acquired remote data are stored in the database of Web server. An agent is activated on receiving updated data from patient side [6, 22]. E-health mobile based MAS [2] solve two problems. First, the patient bound to a room where a device is attached to bed. Second, the devices do not analyze results but provide recommendations. The mobile phone is the devise used to communicate. Another tele-health monitoring prototype system executes on the Personal Digital Assistant (PDA) that sense patient health status and sends this information to the remote server [15]. Further, mobile-based system

locates patient existence through Global Positioning System (GPS) to support mobility [18].

Adverse drug reactions in post marketing surveillance is detected in [4], collecting patient data, analyzing and constructing results with expert's aids. This approach uses Recognition Prime Model that computes the association based on experiences. It is also extended to R-CAST approach for sharing information in team environment.

In practical, the performance evaluation of the IEEE802.15.4/Zigbee in Wireless Body Area Network (WBAN) is demonstrated in [17]. For diabetics patients, a Java based RPM is elaborated in [16]. A rule-based expert RPM system receives data from custom-made wireless sensing device at patient location [19]. The techniques to train the Knowledge-base (KB) are presented in [20].

In general, handling small memory on mobile phones is the principal problem. The key idea is to keep each element of data in presence of huge data rates. Data streams have fast, multiple, continuous and time-varying characteristics [7]. To manage small memory in data processing, approximation technique is used [8, 12] that summarize blocks of data into compact form such that small memory can hold it in any data rate. A data streams management framework proposed in data warehousing domain [11] is focused on approximation and memory management.

To enhance interface layout and consistency on mobile device, application of interface patterns is necessary. Design Pattern is encapsulated solution to recurrent problem, increasing consistency in software development. Mostly, it is used in architecture development, combining multiple standards. Patterns for cross-platform development of web applications are proposed in [10]. Pattern approach for information visualization is presented to enhance the interface design [12]. In Natural Language Interfaces to Databases (NLIDB), multi-modal interfaces describe management for different kind of displays (textual, graphical) on a single layout [13].

3. RPM APPROACH AND TECHNOLOGIES

Due to the increasing development in Information and communication technology, MAS become more feasible to implement. According to [14], web traffic is more than 25% of the overall Wide Area Network (WAN) traffic. Currently, almost every person has access to Internet. Through Internet, agents communicate each others, sharing information about current situation (reactivity). In patient monitoring, some issue are identified: 1) patients cannot be examined anywhere, 2) entities have to stay at only one place, 3) even entities may not hold portable everywhere, 4) patients or staff may not actively manage such as turn on, run application, 5) in emergency condition, patient may not be close to system that can send alert to properly agent. Thus, RPM has been raised as a domain.

RPM works as follows: the agent at patient's location receives updated health condition from monitoring devices; with this information, it treats and analyzes these data and sends recommendations if any to patient, and reports it to doctor agent. Upon this report, doctor agent interacts with specialized agent for producing a diagnosis. In turn, specialist agent transfers diagnosis report to the doctor.

Finally, doctor makes a prescription for proper treatment. During this cycle, recommendation and report are sent to corresponding entities. MAS approach has proved greater flexibility to medical stakeholders, so they do not have to bind in hospital premise only. Tangible benefits are provided to patients at home: they can be treated and monitored [2].

Agents are executed on two types of devices where corresponding information is viewed by the entities as described below.

3.1. MAS Approach

The Patient, doctor, specialist, nurse,... entities are able to view updated suggestions and reports on Personal Computers (PC). Examples of such applications are appointment handling system [5], JAVA based agent development framework [3], adverse drug reactions in post marketing surveillance [4]. They are explained with an example on JAVA based framework: The patient agent running on a PC can only receive current health status when it is under the limited range of the network, also hospital correspondents on emergency condition may be alerted.

No doubt, networks connect millions of users simultaneously. MAS approach requires a device to facility mobility, carrying out relevant tasks anywhere (acquiring and delivering medical services).

3.2. Nomadic Devices

These provide easy connectivity without non-mobility constraints. MAS have also been switched from PC's to mobile technology. Now, patient at home or road can be treated by the medical staff. Using mobile technology, doctors may be alerted about patient condition.

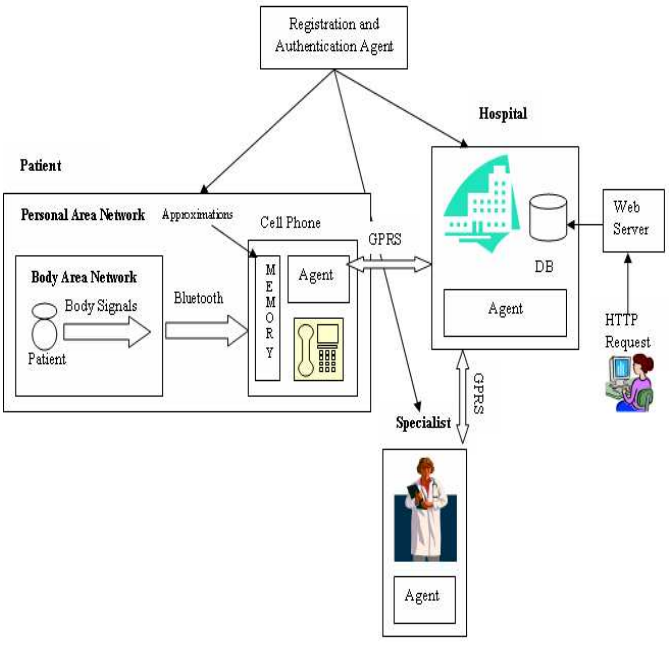

Fig. 1: State-of-the-art Framework of Remote Patient Monitoring

4. OPTIMIZED FRAMEORK FOR E-HEALTH

Upon the needs of mobile and secure E-Health system, we propose a framework that has all enhanced features desired by this sensitive domain. The proposed framework uses only fully robust components (see Figure 1).

In the following sections, we discuss each part of the framework.

4.1. Patient-side Module

This work solves the issues of [2] and improved patient-side module contains following sub-networks.

4.1.1. Body Network

It contains different sensors attached to patient body such as heart monitor (ECG), blood sugar evaluator, etc. The data collected by sensors is transmitted to PAN via Bluetooth. These sensors continuously monitor different parameters of patient and generated data is sent to agents active in Personal Area Network (PAN). The reader notices that these sensors are working completely in wireless environment. Now patient is monitored anywhere in remote location.

4.1.2. Personal Network

It connects the users in Body Area Network (BAN) providing communication among patients, nurses, and doctors in its local range. PAN includes an intelligent agent on mobile phone that takes and analyzes patient data. It then generates reports for remote doctors and specialists that are sent via General Packet Radio Service (GPRS) technology on WAN. Intelligent agent receives data from BAN through the Bluetooth technology.

4.1.3. Buffer Overflow Elimination

BAN sometimes sends fast streams to PAN. BAN overflows buffer after fifteen minutes [2]. To manage limited buffer, approximation techniques [8, 12] are used. Similar problem also exists in data streams applications like telecommunication, financial stock tickers, security sensors, network traffic, etc. generating fast, multiple, continuous and time varying data streams [7]. Such large data cannot be stored in limited system memory. When preventive approach is not used, data will be lost. Therefore, to ensure reliably of secure and complete data transmission is important to perform.

Approximation techniques basically summarize the chunks of data and transforms into smaller units, i.e. approximation techniques extract the essence of knowledge inherent in the data. A popular technique used for approximation is Sampling, Histograms, Wavelets [12], where data is partitioned. After this procedure, small samples containing complete knowledge are picked from each part.

Storage of data streams in real-time data warehouse is presented in [11]. In fact, new applications are introduced in business domains that generate continuous data streams. Extraction, Transformation and Loading (ETL) tools are catered to receive and process stored-only data. Such tools are not capable to handle data streams. Therefore, the framework proposes an extension of traditional data warehousing architecture. It takes data streams, use approximation and flow control techniques to manage the data streams for storage in the data warehouse. Data streams are processed as follows: continuous queries receive data streams and filter only relevant data streams. Irrelevant data streams not fulfills the criteria of continuous queries are dropped. Thus, it reduces data streams size. After filtering, information is stored in short memory. The real problem in processing such data is the small storage. For this purpose, sampling based approximation technique is used that summarize the data streams in compact form to adjust them in memory.

Synchronization between speedy data streams and the processing technology is other main problem. To tackle flow regulation technique, Token Bucket is used in this work. Finally, the complete data streams without losing are loaded in the real-time data warehouse. The approximation to handle buffer of personal area network is taken from [11].

4.2. Nomadic Device Interface

The interface design of mobile phone should be flexible and understandable by the user. The work presented in [13] discusses multi modal interfaces that demonstrate same data on screen in multiple formats such as graphs, text, dialogues, etc. Such presentation of information is more readable for the user in swift glance. In multi modal interface, user can construct query by the selection of mouse from graphs, input text from keyboard and with the guidance of dialogue controller about rules. Similar functionality should also be provided to the user on mobile phone interface to query from databases or to display results. Further, the results generated by agents should be presented on device in the form of text that user can easily understand and read. These should also be presented in graphical form that can be understood by the user.

The system must also connect information from each device on one computerized interface to efficiently represent data [3]. The requirements of mobile phone design are different from desktop computer design because of its small screen size. Even the websites are developed differently for each device. For device interface design, multiple design patterns are proposed [12]. Patterns are solutions to recurrent problems. The patterns are designed on the basis of experiences and used for design consistency on different platforms. Therefore, mobile phone interface design must use these practices to improve the interface.

4.2.1 Improvement of Battery Timing

Battery time of phone is hindrance in continuous connectivity [2]. With on-demand GPRS connection, as discussed in previous section, battery time of mobile is saved more than 50%. Therefore, three way handshake methods solve both problems i.e. reduction of GPRS cost and battery time of mobile.

4.3. Patient agent

It is responsible for receiving patient data; analyzing information using its knowledgebase, and historical data from the database. It then produces recommendations and precautions for the patient. The patient's agent responsibility is also to generate report for doctor and other medical staff. It continuously monitors the patient health and takes timely action in case of alarming condition. This agent works on the patient mobile phone. So, if patient is living anywhere outside home or hospital, he is permanently monitored.

It is important to consider the concurrent executions of multiple agents. For example, two patient agents try to update information in the remote database may override important information of each other. In the same way, multiple patient agents try to access services of same doctor simultaneously. In such situations, how they should be entertained. So, doctor agent may handle priority based scheduling scheme to control such interactions. These responsibilities may be provided to registration and authentication modules.

4.4. On-demand GPRS Connection

Continuous mobile GPRS connection is costly and unaffordable for patients [2]. The communication activity is rare between patient and medical staff by MAS. Therefore, GPRS is wastage of resource and cost. Short Messaging Service (SMS) is a possible solution. For example, to deliver patient recommendation by doctor, a SMS session is the best option. But, for long data transfer, a server database update cannot be carried out with SMS. Each agent should have been provided rights to start GPRS service of other agents at need base for particular situations. The agent wanting to perform communication sends request to establish connection to the target agent. The block diagram in Fig. 1 depicts the GPRS connection process. Assume that patient agent desires to send report to doctor site. The patient agent sends GPRS request to doctor agent. In response, when doctor agent does not have other commitments then it returns positive acknowledgment to the patient agent. Giving this acknowledgment, GPRS connection is activated and data transfer is carried on (see Fig. 2).

The patient agent passes needed parameters to start GPRS service at doctor site. When doctor agent is ready to receive data, an acknowledgment is sent to patient agent. Giving the acknowledgment, GPRS at doctor location is activated and both agents communicate necessary information. Once data has been transferred, patient agent signals about termination of communication. When communication is finish gracefully, GPRS connection is deactivated.

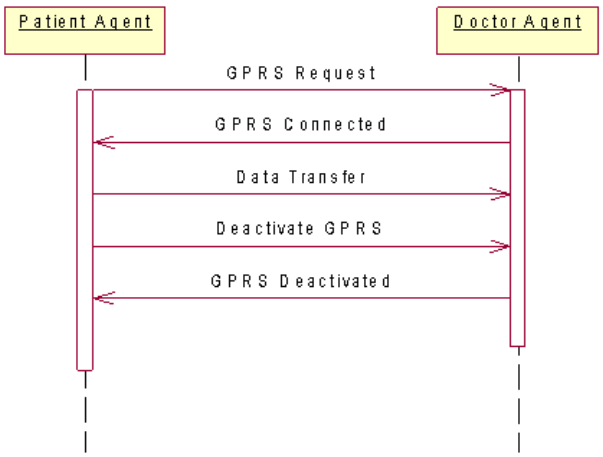

Fig. 2: Sequence Diagram of GPRS connection Procedure

4.5. Registration and Authentication of agents

The job of this module is to register and authenticate the agents. After registration, the agent is recognized by other agents. The services running on the internet have many threats of malwares, spywares, and hacking. The medical domain has high security requirements for sensitive data transmission. If it is insecure, any intruder can change the patient report that is obviously dangerous for his life. MAS work autonomously in the environment with less human interaction. Such automatic software may not understand the intrusion of bad-doers. With these reasons, proposed framework introduces registration and authentication module. It ensures secure communication among different agents.

Further, it has a naming service that provide unique name to each agent working in the real environment. Any agent without the permission of this module cannot be created and start working. Registration and Authentication module has authority to kill any agent harmful for the environment. It is intended to emit a secure social behavior in tele-medicine domain. This component continuously monitors the working of all agents. As discussed in the previous section that concurrency control, error detection & correction, and system recovery must be delegated to the component that has global view. The registration and authentication module has such capability so that it can control these activities.

4.5.1 MAS Security Provision

The interaction among agents is carried out through Internet. Internet is ubiquitous technology and provides information, entertainment, and e-commerce. Thus, Internet is facing many threats likes hacking, sniffing, viruses, worms, etc. The stakeholders that transmit sensitive data through Internet like financial, military data apply security in the form of authorization and authentication.

MAS are also necessitating security control to avoid from malfunctioning and accurate communication especially

in RPM domain where a chunk of information has great importance for life.

4.6. Web Sever

For short information exchange, mobile phone is best option. But, in some situations, heavy data display may be required such as analysis of quality of medication service. The mobile phone has limitations of small memory and display. The web Server is the machine that fulfills requests of its clients (doctor, staff, etc.). The client machines request to the server for retrieving information by specifying the HyperText Transfer Protocol (HTTP) Universal Resource Locator on the web browser.

Let's take an example from remote patient monitoring domain. The doctor agent wants to analyze the trends about patient's health improvement. He sends request to server via web browser like http://www.e-health.com/trends. The Web Server receives the request; search its documents collection for specified page and returns to the client. Upon receiving the page, user (the doctor agent) on client machine formats the query by selecting required options on the web page e.g. age limit, disease type, area, etc. The formatted query is then submitted to the Web Server. In response, Web Server further request to Database (DB) agent for executing query on hospital database. The results are evaluated and formatted by DB agent and supplied to Web Server. Then Web Server dynamically builds a web page to format the results. Finally, web page is transmitted to client machine through network.

4.7. Hospital DB

The DB agent receives request from other agents to perform any activity on the database. The current status of patient is updated in the hospital database. Hospital agents having the roles of doctors, nurses, and staff receive updated patient data from the database, analyze with historical data, and finally generate recommendations and suggestions for the patient. For diagnosis patient disease, specialist agent also use database for accessing data. The hospital database is developed in relational form. The DB agent translates the FIPA ACL [1] message to relational database query and execute on relational database management system.

5. FEATURES FOR COMPARISON WITH EXISTING SYSTEMS ARCHITECTURES

Mobility: The system should keep running in any location. It should not constrain to fixed location. The agents running on mobile are its example.

Security: The whole system must be centrally controlled. Each entity must be authenticated its authorization before interaction (see Table 1).

Recovery: The system should not stop in case of failure in any component. It should have capability to recover from the problem.

Efficient communication: The information from sending entity should be reached instantly to the receiving entity.

Updated technologies: The system should have ability to adapt with newer technologies such as Bluetooth instead of infrared.

Centralized DB: The information in the tele-medical domain must be integrated and consistent in the presence of multiple agents working on that. A centralized DBMS provides integrity of data.

Co-operation: The e-health environment should be accessible in which agents can easily co-operate.

Table 1: Comparison among Different Architectures

Architectures/ Functions	Mobility	Security	Recovery	Communication	Updated Technologies	Centralized DB	Cooperation
Optimized Architecture	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mobile E-health	Yes	No	No	Yes	Yes	Yes	Yes
Web ECG	No	No	No	Yes	No	Yes	Yes
JADE System	No	Yes	No	No	No	No	Yes
Adverse Drug Reactions	No	Yes	No	Yes	No	Yes	Yes
Tele-medical Collaboration	No	No	No	Yes	No	Yes	Yes
Tele-medical Collaboration	No	No	No	Yes	No	Yes	Yes

Table 1 show that existing MAS systems for RPM do not include all above features. We incorporate these capabilities into our optimized MAS architecture. Thus, reactiveness, proactiveness, and cooperation among agents are enhanced.

6. PROTOTYPE SSYSTEM

We have developed a prototype system based on our proposed framework. At the patient terminal, our RPM application on the mobile is setup. The BAN is configured with the non-intrusive wearable body sensors continuously monitor body parameters (blood pressure, blood sugar, environment humidity and body temperature) and send the data through the Bluetooth to the patient agent in the cell phone. The agent performs analysis on the current data and instantly informs the patient and the medical staff in hospital. It alarms the patient with information shown in Figure 3.

Fig. 3: Notification to Patient on Alarming Condition

The registration and authentication agent performs administrative tasks (e.g. authentication of agents, collaboration among agents etc.). The figure 4 demonstrates the authentication of the patient carried out by the registration and authentication agents.

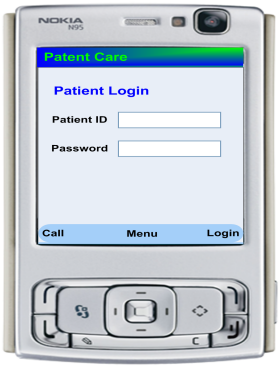

Fig. 4: Authentication of the Patient

7. CONCLUSIONS

Remote patient monitoring is active research area that device techniques to provide healthcare for old, disable and chronically ill patients. We have explored, in this paper, different mobile based tele-health service system approaches that use Multiagent paradigm. During study we found multiple weaknesses in these approaches. Based on our findings we have proposed an optimized framework. The proposed system provides state of the art RPM services in one framework. We have solved significant problems in the existing MAS-based RPM infrastructure such as alternative solution for continuous GPRS connection is provided, a way to increase battery life is proposed and data management in the network is resolved in our framework. Finally, prototype system demonstrates its practical viability. The system work efficiently and securely in the MAS environment.

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