Data Consistency within a Pervasive Medical Environment

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Abstract—**Within a pervasive medical environment multiple sources of static and dynamic datasets exist. A high degree of importance is associated with this data, as medical practitioners prescribe relevant patient care based on the information provided. Pervasive environments contain multiple points of access that allow medical practitioners to read and modify patient datasets using PCs, PDAs and other mobile devices. Enabling medical practitioners to modify a patient dataset introduces a new data consistency problem. Presented is the Data Management System-Data Consistency Model (DMS-DCM). It is designed to intelligently interact with servers, mobile computing devices and patient sensor nodes within a wireless sensor network (WSN). Effective data consistency is a fundamental requirement within health informatics, since it provides the foundation to ensure that medical practitioners receive up-to-date data on time every time. In a distributed dynamic environment multiple views of the same dataset may exist. The DMS-DCM employs a JADE agent platform to ensure that all relevant medical practitioners share a consistent view of patient datasets in real-time. The DMS-DCM experimental prototype is presented.**

I. INTRODUCTION

The Data Management System (DMS) [1] is designed to optimize data management within ubiquitous medical environments. It is essential within a medical domain that all datasets within the distributed environment (e.g. PCs, PDAs and patient sensors) are up-to-date. Classical data management employ two key operations read and write. In relation to data consistency a write operation can not be executed in isolation. It needs to verify that no other user is interacting with the current dataset and that correct datasets are replicated amongst all users. This is referred to as, strong data consistency [2]. The DMS-DCM applies a similar approach to the view-based consistency of [3]. Following this method, data objects of a view are only required to be updated before they are accessed. This ensures that medical practitioners receive the latest datasets upon request. A multicast-based middleware is presented in [4]. In our system JADE agents provide similar data retrieval and dissemination techniques within our pervasive environment. The DMS-DCM is a novel approach in managing data consistency by employing context aware reasoning JADE [5] agents within a data rich pervasive medical environment. The JADE software agent middleware provides the necessary functionality to manage our pervasive datasets. The DMS-DCM shares similar qualities to [6] where cooperating mobile agents work in unison to ensure data consistency is maintained.

The DMS-DCM architecture is built on two main datasets: core patient data (i.e. patient vital signs, patient history etc.) and context parameters (time, location, profile etc). By combining these two sets of data in the DMS-DCM model, data consistency techniques may be enhanced. For example, a patient is wearing the Tyndall-DMS-Mote (T-DMS-M) (cf. Figure 1). Pulse rate sensor readings are sampled and transmitted to the DMS-Server. One medical practitioner may update his/her PDA with extra information alongside the current real-time sensor values. Based on the context of the patient, medical staff and the state of the core patient dataset, JADE agents with built-in reasoning parameters may dynamically decide which datasets need to be replicated within the pervasive network. This approach takes advantage of all known real-world information in relation to its environment and enhances data management to achieve two key goals: to provide medical staff with relevant data on time, and to reduce information overload, thus save on bandwidth.

Figure. 1. A Tyndall-DMS-Mote (T-DMS-M) transmitting real-time vital sign patient data back to the DMS-Server through a Nokia 9500 Communicator (smart phone).

In section II of this paper the DMS-DCM architecture is presented. It describes the agent-based architectural framework and the data consistency techniques employed by the JADE agents. An evaluation of the DMS-DCM model is outlined in section III. Finally, section IV concludes with summary remarks on the DMS-DCM and on future research.

II. DMS-DCM ARCHITECTURE

The data consistency techniques employed between medical practitioner mobile devices and central medical servers is built into an agent-based architectural framework (i.e. JADE). This strategy enables mobile medical devices to contextually retrieve, pool and disseminate relevant real-time information to neighbouring medical practitioners and medical servers.

The logical interaction between medical practitioners and the DMS-Server is shown in Figure 2. This diagram highlights a sequence of intercommunication amongst agents and external patient sensors within a wireless sensor network.

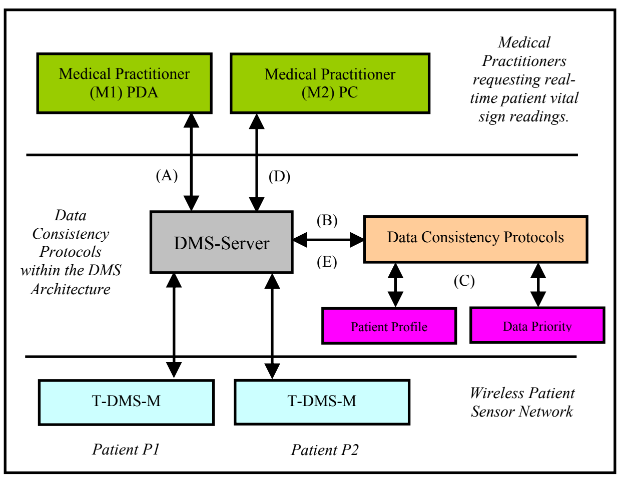

Figure. 2. DMS-DCM Architecture. (A) A medical practitioner M1 requests patient data from patient P1. (B) Consistency protocols are executed before passing the real-time sensor data onto medical practitioner M1. (C) To save on bandwidth overheads only relevant data is replicated based on the patient profile and sensor data priority. (D) Medical practitioner M2 requests real-time patient data from Patient P1 in parallel to M1. (E) Jade software agents within the DMS-Server replicate all know datasets on M1s PDA and correlate this data with M2 and P1 real-time sensor readings, thus providing a higher QoS. M1 and M2 now share a consistent view of the patient data set including real-time vital sign readings.

The DMS-Server [1] runs in parallel with DMS-DCM protocols (JADE agents). Here all datasets are prioritised, filtered, and transmitted based on the context of the patient, medical staff and their associated environments. This is achieved by employing the following protocols:

A. Profile

A pervasive medical environment may generate large amounts of data. This may result in data overload, poor Quality of Service and potentially, fatal patient care. The introduction of user profiles adds a new dimension to patient data management within a pervasive environment. Presented in [7] is the DMS-User Profile (DMS-UP). User Profiles are utilised to effectively manage the delivery of relevant information to a practitioner's mobile device, thus improving the QoS. Similar approaches have been applied to overcome network disconnection and/or limited bandwidth [8].

B. Priority

Data consistency may employ various forms of data replication, where specific or entire datasets are copied to a variety of clients and/or servers. In relation to the DMS-DCM, patient, staff and environment variables are prioritised. This enables the DMS-DCM to update scheduled medical practitioners with correlated and relevant real-time information.

The Role of Context

The advantage of integrating a context sensitive data caching technique is outlined in [9]. Here relevant data is cached to neighbouring nodes based on the locality of the mobile user within a wireless network. The DMS-DCM protocols are based on the same philosophy. Merging the profile and priority of patient/staff with the context of the environment (e.g. identity of staff, location, time etc) decreases the levels of inconsistency within the pervasive computing environment.

An outline of some of the key software agents and their interaction between medical staff and specific datasets is presented in Figure 3. An overview of three of the main software agents is given:

Mobile Device Manager Agent (MDMA)

This is a resident software agent (i.e. JADE) designed to arbitrate between the central DMS-Server and medical practitioner. The agent deals with medical staff requests and incoming server updates. The MDMA interacts with the Mobile Device Data Consistency Agent for pre and post data consistency checks.

Mobile Device Data Consistency Agent (MDDCA)

Incoming and outgoing datasets to and from the mobile device pass through the MDDCA. This agent is responsible for ensuring that not only is the current dataset updated but that all related datasets are resident on the device. It achieves this by interacting with the Central Data Consistency Agent.

Central Data Consistency Agent (CDCA)

The CDCA manages all real-time sensor data streams and medical practitioner read/write update/requests. CDCA executions are based on the central expert system,

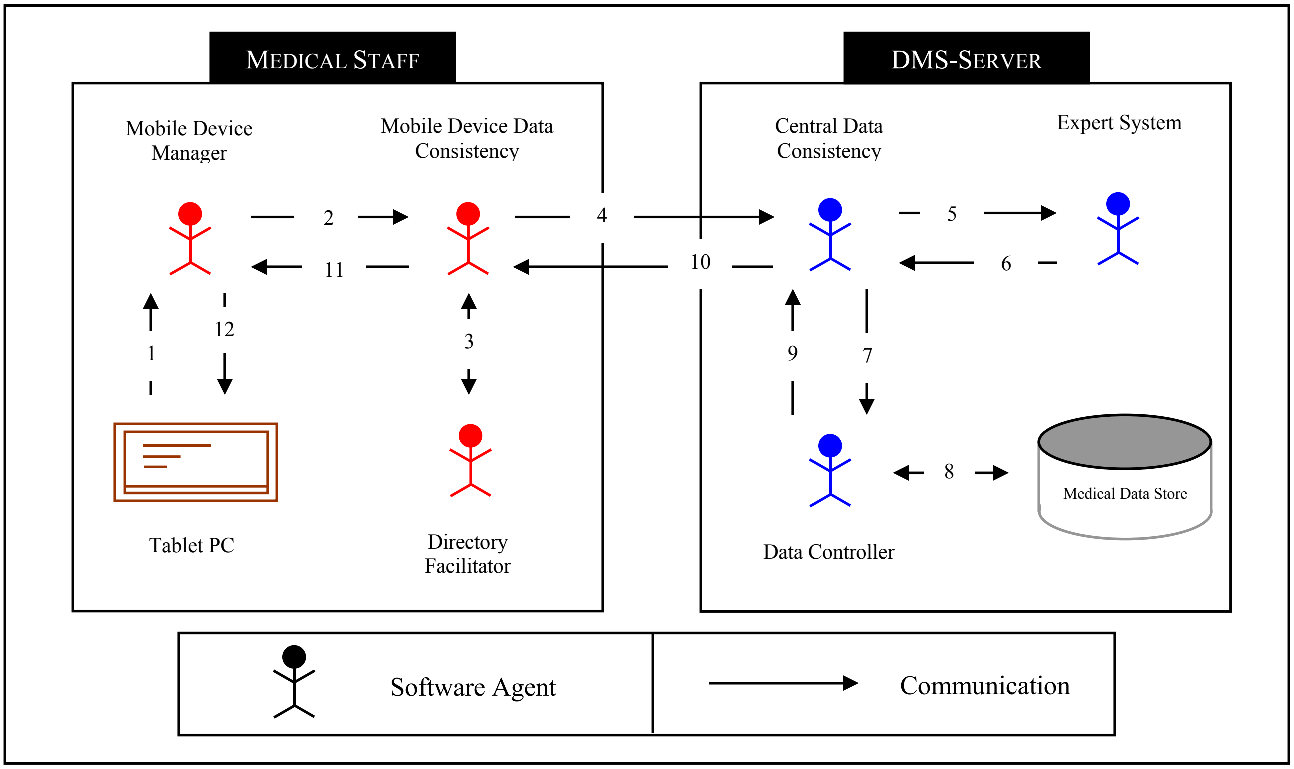

Figure. 3. The DMS-DCM Agent Based Architecture.

which contains a formal set of data consistency rules. All DMS-Server datasets are stored in the Medical Data Store; this includes sensor readings and database records.

III. EVALUATION

The current DMS-DCM prototype has been implemented to evaluate the performance of the agent-based data consistency protocols. Experiments were conducted to evaluate the effectiveness of DMS-DCM's broadcasting (server to client) and sampling (based on client requests) capabilities. Presented are two data consistency scenarios. For both experiments patient pulse rate readings were sampled over a 4 hour period (240 minutes). Sensor readings were stored within the medical data store for analysis.

EX1: Periodic Sampling within a Simulated Environmant

Presented in Figure 4 are the results of this experiment. Three broadcasting periods (server to client) of five, ten and fifteen minutes were applied. Here patient datasets including the pulse rate readings were transmitted from the DMS-Server to scheduled medical practitioners. For a 15 minute broadcasting period, 16 transmissions are made. This had the effect of leaving the medical practitioner's mobile device out of synch (i.e. inconsistent) for 19% of the total time or 46 minutes approximately. A summary of the three periodic broadcasting intervals within the simulated environment are given in Table 1.

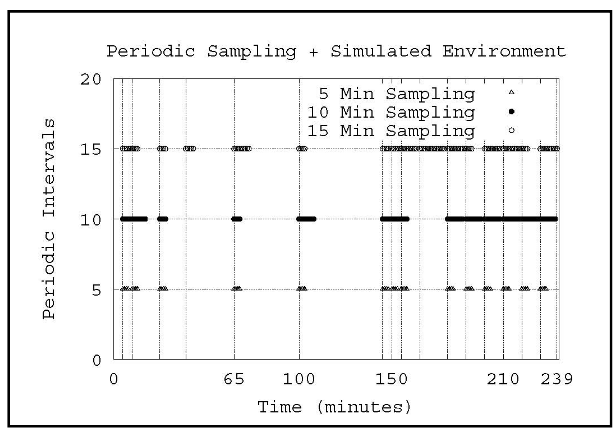

Figure. 4. Periodic Sampling within a Simulated Environment. Vertical dashed lines represent sensor value change (e.g. pulse reading goes from 80 bps to 83 bps at time 65 minutes)

EX2: Priority Based Context Sampling within a Simulated Environmant

This experiment was executed in a similar manner to EX1. Here the central data consistency agent applies a priority based protocol. This resulted in pulse reading transmitted (to medical practitioners) which had increased or decreased by a factor of 5+ bps. The results demonstrated in Figure. 5 still show an inconsistency. However, as these inconsistencies are of no real importance in the context of the current patient (pulse rate change of less then 5 bps). A logically complete consistent view now exists. A total of 8 context transmissions were made compared with the 16 transferred for the 15 minute periodic updates. The key advantage of the priority context based transmission is that it only transmits context relevant data. This may save on bandwidth usage (dependant on sensor activity) and cut down on information overload. Importantly it delivers relevant data in a timely manner to assist the medical practitioner in providing a higher QoS.

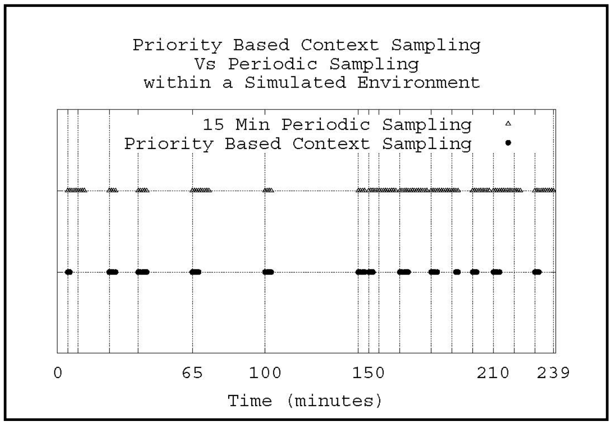

Figure. 5. Priority Based Sampling. Only pulse rates of 5+ bps (beats per second) are transmitted.

TABLE I. INCONSISTENCY TIME PERCENTAGE BASED ON VARIOUS SENSOR ACTIVITY AND PERIODIC SAMPLING INTERVALS.

	Periodic Intervals		
Rate of Sensor Change	***5 Minutes***	***10 Minutes***	***15 Minutes***
20 Minutes	10%	35%	39%
10 Minutes	20%	70%	64%
2 Minutes	80%	90%	93%

IV. CONCLUSION

Presented is the DMS-DCM (Data Management System-Data Consistency Model). It is designed to intelligently organise the large quantities of data within our pervasive medical environments. Two protocols were outlined, Priority and Profile. The DMS-DCM merges context related consistency protocols with known context information to deliver relevant real-time information to medical practitioners. This is achieved by formally defining context rules within an expert system.

Data sources which may reside on a medical practitioners mobile device is associated with specific members of the medical staff. This ensures that any context update which occurs within the mobile device is transmitted to key members of staff. This ensures that all relevant information is available and patient care is improved. The DMS-DCM is built on top of an intelligent agent middleware JADE. This enables mobile devices to interact with JADE compliant clients and servers in a context manner.

The current DMS-DCM prototype indicates that issues such as data overload and bandwidth usage may be improved. It also signifies that relevant real-time information may be contextually delivered to assigned members of the medical staff, thus improving the QoS.

To fully evaluate the run-time capabilities of the DMS-DCM architecture, dynamic assignment of patient and subsequent patient dataset priorities need to be applied.

ACKNOWLEDGMENT

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