

A COMPLETELY DECENTRALIZED WORKFLOW MANAGEMENT SYSTEM FOR THE SUPPORT OF EMERGENCY TELEMEDICINE AND PATIENT MONITORING

E. Kyriacou¹, *Member IEEE*, G. Fakas², V. Pavlaki¹

Abstract— In this work we propose a completely decentralized workflow system, based on Peer to Peer (P2P) computing, in order to support the procedures followed a) when handling a patient in a hospital emergency health care department b) telemedicine services needed during emergency cases or during remote patient examination and monitoring. The proposed architecture is an addition to an already existing telemedicine system that enables telediagnosis and long distance support during emergency and monitoring cases. The existing system is based on a client server architecture, which has dependability limitations as it depends on a single centralized machine. Dependability is a critical requirement for such cases; so the new proposed system addresses these limitations by facilitating operation and even when some peers are unavailable for any reason. Concluding, the system design has been completed successfully.

I. INTRODUCTION

Telemedicine can be used in order to improve health care during emergency cases or during patient examination being performed in understaffed rural or remote areas. The provision of effective emergency Telemedicine and patient examination/monitoring solutions have been discussed for several years [1]. There are a wide variety of examples where these fields are crucial. Nevertheless, ambulances, Rural Health Centers (RHC) or other remote health location, ships navigating in wide seas and airplanes in flight are common examples of possible emergency sites. Furthermore having in mind that prevention is better than treatment. For example, in the assessment of cardiovascular diseases, early and accurate diagnosis of the risk of cardiovascular events, such as strokes, can be crucial for patient's life. This can only be achieved by specialized tests, which are not easy to be performed if understaffed remote areas.

Until now several systems have been proposed in order to support the above mentioned needs. Most of these systems, including a system proposed by our team, are based on centralized client server architecture [2]. Almost in all cases the telemedicine units were located near the patient while a server was accepting the call for connection from these units

Manuscript received April 3, 2006. This work was partially funded through the project Integrated System for the Evaluation of Ultrasound Imaging of the Carotid Artery (TALOS), of the Research Promotion Foundation of Cyprus.

¹Department of Computer Science, University of Cyprus, Nicosia, Cyprus, ekyriac@ucy.ac.cy, twister@cytanet.com.cy

² Department of Computing and Mathematics, Manchester Metropolitan University, Manchester, UK, G.Fakas@mmu.ac.uk

so as to help doctors provide expert help to those handling the patient.

Several flexibility and reliability issues can be addressed during the above mentioned cases. For example what happens when a server that is the central node of such a system fails to support connections requested by multiple telemedicine units? This could happen during several cases such as:

- Server failure
- Network failure or network unable to support more than a certain number of connections; this could happen when too many telemedicine units are requesting connection due to a mass destruction such as earthquake, terrorist attack or even a car accident with too many victims.

Following these needs and trying to support an already existing telemedicine system, we propose a decentralized workflow system for the support of telemedicine services needed during emergency cases or during remote patient examination and monitoring.

The integration of workflow management facilities in such scenarios could add the following contributions:

- **Open and flexible definition of medicine processes.** The use of Workflow Process Definition languages facilitates interoperability and also a lot of flexibility. For instance, in the case of any requirements changes we will no longer need to change any hard programming code but only the process definitions which are programming language independent.
- **Dynamic and automated execution of medicine processes:** the workflow engine will automate the execution of these medicine process definitions.
- **Enhanced Workflow administrative and management facilities:** workflow technologies will facilitate automatic control of medics workload, the need for reallocation of work, need for call for more resources, use of deadlines etc. We can also monitor the current state of any patients' diagnosis, treatment etc, monitor any delays in response to allocated work to medics.

The new decentralized workflow management system will take advantage of potentials of the Web Workflow Peer (WWP) [3]. A WWP is a processing entity that facilitates users to participate, administrate and manage workflow processes in a completely decentralized fashion.

II. METHODS

The aim of this new system is to automate processes that take place in the emergency health care department ER of

Nicosia General Hospital during an emergency incident or in a cardiovascular clinic during remote patient examination. This will be performed using a decentralized workflow architecture in contrast with the existing solutions that use a client-server architecture.

A. Emergency Health Care Department of Nicosia General Hospital and the Existing Emergency Telemedicine System

The Nicosia General Hospital is located in Nicosia which is the capital of Cyprus and the Accident and Emergency (ER) Department is responsible for all the emergency incidents that happen in Nicosia City and the near suburbs. The department has 120000 incidents annually out of which 8000 include ambulance transportation, with the rest of the incidents concerning patients carried to the department either by relatives or arriving by their self for not severe cases such as minor injuries.

The department is currently being supported by a telemedicine system [1] which is installed in ambulance vehicles and is able to transmit several biosignals from a moving ambulance to the department thus enabling expert doctors instruct paramedics and ambulance personnel how to treat several cases that need specialized health care.

In order to define workflows that will be able to help the department's operation, we have defined two processes which are: a) telemedicine connection of an ambulance vehicle with the ER department (telemedicine process), b) treatment of patient in the department (patient treatment process).

B. Cardiovascular Patient Examination

Stroke is the third leading cause of death in the Western World and the major cause of disability in adults. Carotid stenosis is the largest single aetiological factor known to produce focal cerebral ischaemia, but in those with carotid bifurcation disease, only a minority give warning symptoms, the majority having their stroke from previously asymptomatic lesions. Since morbidity and mortality after acute stroke is unacceptably high, it is very important to recognize and to treat patients with carotid bifurcation disease before they develop symptoms [2]. A lot of work has been done by our team in helping experts identifying patients' risk of stroke. Nevertheless the identification of these patients can only be done with the help of specialised and expert personnel, this is not always possible when patients are located in isolated and remote areas. In order to support this process (patient cardiovascular examination) we have defined a workflow which is similar to the emergency telemedicine workflow mentioned above.

C. Decentralized workflow and definitions

Several decentralized architectures which provide different solutions have already been introduced [3]-[5], [7].

The proposed system is based on the Decentralized Workflow Definition Language proposed in [5] and the P2P Workflow Management and Administration proposed by

[3]. We consider that each peer has its own task-role-activity to perform. Each peer can perform more than one task-activity and therefore may belong to more than one roles.

Peer-to-peer (P2P) [9] is a style of computing that allows any device to interact with any other computer on the network. In effect, P2P turns every device into a client and a server, enabling a much more symmetrical and decentralized communications model for applications, services and users.

Workflow Management System [6] is a system that completely defines, manages and executes "workflows" through the execution of software whose order of execution is driven by a computer representation of the workflow logic.

A P2P Workflow Management System is a workflow management system that is completely decentralized facilitating direct interaction between peers.

D. States of Peers and Activities

Each peer can be in one of the following states:

On-line: where the peer can receive new work;

Off-line: where the peer is not available to receive new work. New activities may be on hold until the off line peer returns on line or even allocated to alternative peers. Peers before permanently leave may notify this otherwise the initiator peer may decide to treat any other peer failing to respond as permanent. For the processes activities where the peer is temporarily off line, the execution of the process will continue, if possible, in this case when the peer returns some synchronization may be required or alternatively the execution will have to wait until the peer returns.

Each workflow activity could be in one of the following states:

- **Initiated:** a new process has just started, this is where the initiator peer starts it.
- **Received:** a service has arrived from the previous peer and is waiting until all conditions are true and the current peer is available to start running it.
- **Running:** the peer is running the activity.
- **Aborted:** the peer failed to complete the job either because the peer went off-line or for any other reason.
- **Completed:** the peer completed the work.
- **On-Hold:** the work is completed but the next peer is not available yet to receive the work.
- **Rejected:** the peer rejects to complete the given job.

E. Workflow definitions

Based on the processes defined in sections II.A and II.B we define the following workflows:

1. Telemedicine Process

The telemedicine process is being performed when an ambulance vehicle is handling a patient [1].

During this process the telemedicine unit collects data from the patient, biosignals (3-12 lead ECG, SPO2, NIBP, IBP, Temp) and images of the patient and transforms them to an expert doctor in order to support the personnel handling the

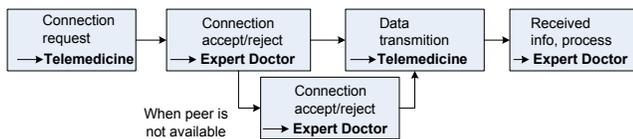


Figure 1. Telemedicine session process

patient at the remote place.

The doctor is able to receive data from the telemedicine unit, process them accordingly and send information back to the telemedicine unit.

Through this process we have four kinds of activities, each one delivered by two different peers, the peer-telemedicine and the peer-expert_doctor. The peer-telemedicine will always act as the administrator because it will always initiates the telemedicine instance process and the peer-expert_doctor will always act as the participating peer.

Peer_expert_doctor can be available or not when asked for connection from a Peer_telemedicine. When not available the connection request is forwarded to the next available peer. The Peer_expert_doctor can be located in the ER department connected on the local network or outside the ER and can be on-call for an emergency incident support.

The peer_expert_doctor has two states (on-line and off-line) and the activity that is being performed can have the following states: **Running** (the peer-expert_doctor can only handle one incident at a time), **Aborted**, **Completed**, **On-Hold**.

The peer_telemedicine can be either on-line or off-line and the activities it performs can have the following states: **Initiated**, **Running**, **Aborted**, **Completed**, **On-Hold**.

If a peer-expert_doctor suddenly has to depart from the ER department, this peer has the obligation to assign the incident to the first available peer-expert_doctor and then depart. It is crucial for the participating peers to inform all other participating peers about the state of the process.

2. Patient Treatment Process

This process starts when a patient enters the ER department, regardless of the way the patient has arrived (on his own or by ambulance).

The first action performed is the recording of personal information of the patient and the assignment of a unique incident number. Then the first available doctor is assigned to the incident. The doctor receives all previous information regarding the patient/incident and records all the information concerning exams and actions performed in the ER department. These exams include recording of parameters like Blood Pressure, ECG, Pulse, Oxymetry or tests like the Glasgow scale test. The doctor has the ability to retrieve any available information concerning previous incidents of the patient from the ER database. The doctor is responsible to decide whether the patient can leave the hospital or move to another department and thus the incident will be considered as finished.

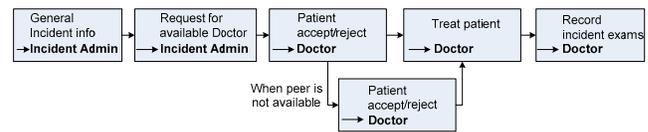


Figure 2. Patient Treatment process

Through the incident handling process (Figure 2) we conclude that we need a peer-doctor and a peer-incident_administrator. The doctor will handle the incident assigned to him from the administrator. In every workflow instance the peer-incident_administrator will always initiate an incidence process instance, while the peer-doctor will act as a participating peer.

In this workflow process we have five activities/roles. The peer-doctor can be online or off-line and have one of the following states: **Running** (the peer-doctor can only handle one incident at a time), **Aborted**, **Completed**.

Soon after the assignment of an incident to the first available peer-doctor, a notification message is sent back to the peer-incident_administration. Upon finishing the actions, the patient can depart from the ER and a notification message is sent to the peer-incident_administrator, notifying him that the incident process is finished and a new incident can be assigned to him. The peer-incident_administrator can be either on-line or off-line and the activities performed can have one of the following states: **Initiated**, **Running**, **Aborted**, **Completed**, **On-Hold**.

3. Patient Cardiovascular Examination Process

This workflow process can be covered by the workflow described for the telemedicine session. We can split the participating peers into two groups which are again peer-telemedicine and peer-expert_doctor. The difference in this case is that apart from the biosignals the telemedicine unit will forward Ultrasound video/images of the carotid arteries in order to help expert doctors identify the risk of stroke [2].

F. Notification Mechanism

We will use a notification mechanism based on three different process management reports to identify the status:

- **Process Current Status:** the system is able to report the current status of a process instance (sending info, receiving info, processing info);
- **Process history:** to report the process history (i.e. process path, participating peers etc);
- **Process Status Report:** to report information such as process total running time, current activity and its status (Waiting Time, Deadline, current WWP), peer's workload etc.

G. Synchronization mechanism

When a peer returns on-line again it needs to synchronize his data [3]. That includes the following activities:

- Notify other peers about his return to the network
- Receive any on hold work from other peers.

- Synchronize the status of processes and activities instances. That may be a long process if there is a lot of work there waiting.

H. Designated Peers

As we can derive from our workflow process in our system we have three types of peers (nodes):

- **Peer-incident_administrator**
- **Peer_telemedicine**
- **Peer_expert-doctor (the same as the peer-doctor)**

Each peer in the system will maintain a repository with the workflow process and workflow Activity Definition that each participating peer may be interest in.

III. RESULTS

A possible example of a workflow process that could take place during a telemedicine session could be described as shown in table 1. The workflow process could have the following steps: a) a peer_telemedicine (Pt_1) is requesting for connection thus initializing the process, b) the first peer_doctor (Pd_1) is not available and the connection request is being forwarded to the first available peer_doctor (Pd_2), b) after the first available peer_doctor (Pd_2) was found a connection between the two is established, c) for any reason Pd_2 has to close the connection, d) the connection is forwarded to the next available peer_doctor (Pd_3), this could either be done by the Pd_2 or if the Pd_2 just disappeared due to a possible problem. The Pt_1 should start looking for the next available in the peer_doctor.

This could be a possible process instance which could not get successfully finished by a centralized process, but it could finish successfully if a decentralized workflow management process is used.

IV. CONCLUSION - FUTURE WORK

The advantages of decentralized workflow management and how they could be used in order to improve the process followed, during patient treatment in an ER department or during patient examination and support through telemedicine, are the issues discussed in this paper.

In this study the initial work performed before moving to the actual system development is presented. This is going to be the future work basically for the telemedicine session so as to be able to have a system that will be able to work under different circumstances. Furthermore, the distribution of data saved during the several processes will also be investigated in order to eliminate the possibilities for data loss.

Workflow Activity definitions

Process name	Pt_1: Telem. connection	Telem. Connection	Telem. Connection
Activity name	Pt_1: Telem. conn. Request	Pt_1, Pd_2: Connection established	Pt_1, Pd_3: Connection established
Input	None	Pt_1, signals	Pt_1, signals
Output	Connection request	Doctor support	Doctor support
Invokedbys	Initiator	Pd_1	Pt_1
Invoking Peers	Pt_1, Pd_1	Pt_1, Pd_1, Pd_2	Pt_1, Pd_3
Preconditions	None	Pd_2 available	Pd_3 available
Postconditions	None	Connection is ok	Connection is ok

Notifications

Process name	Pt_1: Telem. connection	Telem. Connection	Telem. Connection
Activity_Id	Pt_1, Pd_1:	Pt_1, Pd_2:	Pt_1, Pd_3:
Current_Peer	Connection request	Connection ok	Connection ok
Type	Waiting for connection	Connection established	Connection established
Notifying peers	Pt_1	Pd_1	Pt_1

Table 1. An example of telemedicine workflow process

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