Adopting Rule-Based Executions in SOA-Oriented Remote Patient Monitoring Platform with an Alarm and Alert Subsystem

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Abstract. Monitoring and event handling are important aspects in the EU funded REACTION project and its remote patient monitoring services. The REACTION platform is designed to let any application to be able to react ubiquitously to change in a patient's health state and environment and perform pre-defined activities such as alarm handling according to pre-programmed rules. This paper presents and discusses the platform's alarm and alert handling system out of technical perspectives.

Keywords: Alarm handling, Remote Patient Monitoring, Rules, XSLT, SOA.

1 Introduction

REACTION is a research and development project, partially funded by the European Commission, for devising and implementing a platform allowing the remote management of medical data related to diabetes patient's treatment and health care. The strict control of blood sugar levels is necessary for assessing precisely patients' insulin doses in every specific situation. A tight blood glucose level control requires frequents measurements and complex algorithms for assessing the insulin dose needed to adjust for short term variations in activity, diet and stress. One of the main features of REACTION is to provide a safe environment by minimizing, but still managing potentially life-threatening situations. Therefore, the platform offers closed-loop feedback to patients, carers and healthcare professionals with important information for effective control of blood glucose levels in all situations. The ultimate goal is to minimize health risks and improve the lives of patients [1]. In this paper we present and discuss the alarm and alert handling system of the REACTION platform.

B. Godara and K.S. Nikita (Eds.): MobiHealth 2012, LNICST 61, pp. 437–444, 2013.

2 REACTION Notification System

The REACTION's Notification System allows healthcare professionals to pre-define notifications and activities to be performed according to a set of pre-defined rules based on individual changes in patients' health status and/or their environment. These notifications, in turn, will facilitate the day-by-day work of healthcare professionals, as well as formal and informal carers, in addition to provide support to patients related to their individual health status. The system is based on a closed cycle that involves patients, healthcare professionals and the informal carers.

It combines the orchestration of services with an underlying efficient networked-based event management solution. The system is composed by the *Global Settings, Alarm Handling, Alarm Tray Details, Personalized Settings* and *Reports.*

The *Global Settings* contains the Rule editor and the Notification editor. The aim of the Rule editor is to set global thresholds in order to identify patients' adverse events based on the analysis of the received information. By default any new rule is defined to be applied to all the patients under the same pathological condition. It is possible to Add/Remove global rules, as well as to combine different parameters such as age, weight, blood glucose, etc. The Notification editor sets the communication channels that will be used (email, short message service or other), the level of the notification (advice, warning, critical), which is associated with different colours (green, yellow and red) depending on the severity of the event.

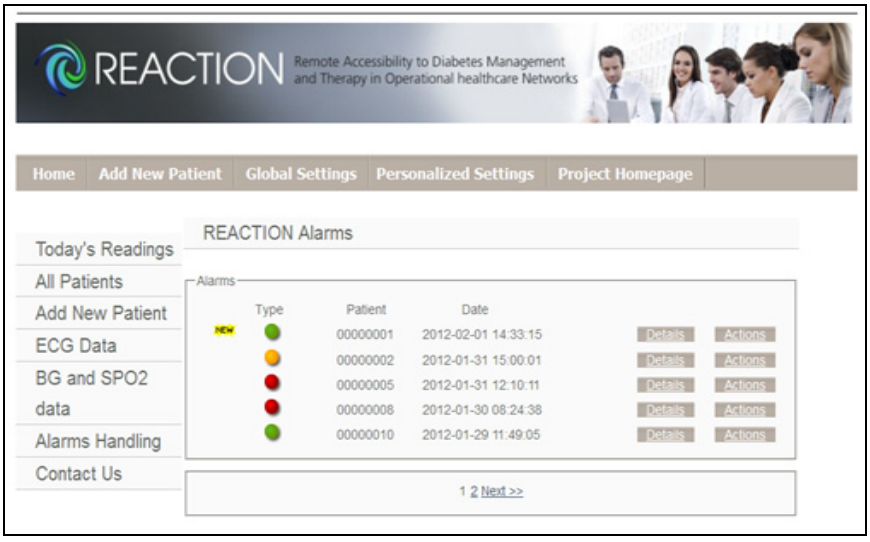

Fig. 1. Alarm Handling Graphical User Interface (GUI)

Fig 1 represents the *Alarm Handling,* where it is possible to visualize the alarms list to better follow the events in the system. The information displayed is the type of alarm, the time and status of the alarm management. It is possible to visualize the alarm details and to enter manual actions required in each specific case. The aim of

the *Alarm Tray Details* is to allow the study of the reasons for the alarm, to analyse the different parameters stored in the system (Electrocardiograph (ECG), blood analysis results, etc.) and to know in details the patient status. With this functionality, clinicians will be able to introduce additional actions manually and generate reports.

The *Personalize Settings* (divided in patient selection, alerts and rule editor) module contains the global settings applied by default that can be adapted to the individualized patient's features; it is possible to filter data by status, name or NHS ID (National Health Service Identification). The thresholds can be modified if needed and different ways of communication can be configured for a particular patient. Finally in *Reports*, the clinicians can personalize the information required and add extra information in order to generate .Pdf files summarizing the status of the alarm and the actions taken. It is possible to add to the report snapshots of the parameters, annotations, tables, etc.

3 LinkSmart Web Service Exposure and Rules

The REACTION project uses the former FP6 EU funded project results of the Hydra Middleware [2] (today called LinkSmart) and its semantic model-driven architecture. By a secure Peer-to-Peer (P2P) tunnelling REACTION is able to exploit remote control of medical devices in diverse patient environments [1]. The REACTION platform is based on a Service-Oriented Architecture (SOA) model [3] that supports the collection of loosely coupled services that communicate with each other and where ensembles of them are orchestrated by a specific high-level workflow using the REACTION Service Orchestrator. The rules are executed at any new received data in both automatic and manual transparent way to the end-user facilitating usability.

3.1 Declaring Rules by XSLT

In REACTION there is a need to process incoming events, mainly observations, and for instance generate different types of alerts and or alarms. Event-driven architectures especially in combination with service-oriented approaches are a topic that has drawn much attention recently. The advantage of event driven system is that it provides a loose coupling between different subsystems which provides flexibility.

When an event occurs then a transition (change of state) take place and any alarm responses can be initiated by the occurrence and detection of events corresponding to a pre-defined scheme. In real life, events are typically combined to yield more accurate assessment of the situation (e.g. is the blood sugar level higher than 7.0 mmol/L? AND has the patient been eating within the last 20 minutes?).

The REACTION Data Fusion Engine is able to aggregate data monitoring events with the semantic annotations provided by the REACTION Context Manager. This fulfils the project's strive for the multi-parametric monitoring where methods for fast and reliable evaluation of complex conditions are implemented.

In order for clinicians to express how different events and combinations of events are to be processed we need to provide mechanisms that make it easy to configure

rules. These rules are expressed using the Alarms and Alerts GUI, in a semi-natural language form. This includes setting up the rule triggering criteria as well as defining the actions to take. The rules that are entered are translated into an eXtensible Stylesheet Language Transformation (XSLT) format [4]. The use of XSLT then allows easy matching of the rules against the incoming Health Level 7[1] (HL7) message [5] in eXtensible Markup Language (XML) format.

An important aspect of the rule engine is that this approach makes it possible to individualise monitoring schemes for patients depending on the clinician's knowledge of the patient health status.

3.2 Executing Set of Rules

Monitoring and event handling are important aspects of the services and by combining the orchestration of services with an underlying efficient networked-based event management solution a set of pre-programmed rules are able to react ubiquitously to change in the patient's health state and perform some defined activities such as raising an alarm.

Since every device, application and subsystem in REACTION is available as a Web Service (WS), these components can easily be incorporated into the action part of the rules, and used when a rule is triggered. This makes the rules very powerful and the system extensible and customisable to meet different application needs. It is also possible to prioritise the rules depending on their importance in different situations. In certain situations it might be more critical if the blood glucose is out of range then if the blood pressure is, and vice versa.

4 Feedback Generating Services

The main objective of the SMS service is to provide advanced and targeted alerts and notifications to end users, with the use of an instant communication method, the Short Messaging System (SMS), which is available over Global System for Mobile Communications (GSM) networks, to mobile users.

4.1 REACTION SMS Alert and Notification system

The key issues for this service is the advanced user profiling and the cognitive techniques which should be used in order to dynamically compose and send alert and notification messages to the REACTION platform end users, depending on their personal profile and attributes (carers or patients). In general, SMSs are sent as:

- Notifications: If all the requested readings from the sensors have been successfully received, stored and properly examined by the system in the central database, a confirmation SMS is sent to the patient. The text message in this case is also predefined and the purpose of its transmission is basically to reassure the patient that all the readings have been properly received.

[1] Framework on related standards to exchange, integrate and share electronic health data.

- Alerts: This function is used for transmitting warning SMSs in order to alert both the carers and the patients, in case the readings received by the REACTION medical sensors used by a patient, show a recrudescence of their vital signs, or in case a serious health risk is detected by the system. These messages will be automatically triggered by the platform, in cases where the data received from the sensors is below or above individually desired levels. This kind of data examination is performed in the central REACTION database through the Rule Engine services. SMS messages may also be composed by carers, through the official REACTION carers' interface. In this case the SMSs are dynamically generated, providing the superintendent carers with the option of writing targeted SMS messages to their patients, including specific medical instructions.

Why use SMS for alerting? SMS is a globally accepted wireless service that enables the transmission of alphanumeric messages among GSM mobile subscribers. The initial version of GSM's short message service was limited to 160 characters per message. Despite that limit, the service became very popular in Europe as a mechanism to exchange text messages between various devices, such as GSM phones, laptops, tablets, Personal Digital Assistants (PDA) and others.

SMS is actually a store-and-forward service that is based on a Short Message Service Center[2] (SMSC) which operates as the store and forward system. Messages can be sent or received over both GSM and General Packet Radio Service (GPRS) channels. GSM uses a large number of logical channels which are mapped onto the physical channels in the radio path. The logical channels are divided in two categories: 1) the Traffic Channels (TCH), and 2) the control channels.

The *control channels* consist of Broadcast Control Channel (BCCH), Common Control Channel (CCCH) and the Dedicated Control Channel (DCCH). The BCCH is a one-to-many unidirectional control channel for broadcasting information from the Base Station (BS) to the mobile terminals (e.g. mobile phones). The CCCH is a point-to-multipoint bidirectional control channel primarily intended to carry signalling information, necessary for handshaking and access management. Finally, the DCCH is a point-to-point, directional control channel. SMS messages are carried from the terminal to the base station over the DCCH channel which consists of the Stand-alone Dedicated Control Channel (SDCCH) and the Slow Associated Control Channel (SACCH). The SDCCH is used before the mobile terminal is assigned a traffic control channel (TCH). It is used to provide authentication to the mobile terminal, for voice call setup and location updates, as well as assignments of TCHs. It is also used for system signalling during idle periods. A slow associated control channel (SACCH) can be linked to either a TCH or a SDCCH. This is continuous data channel carrying information from the mobile, like, for example, measurement reports of received signal strength.

SMS messages are carried on either SDCCH or SACCH depending on the use of the TCH. When the TCH is not available, for example, when there is no voice call or data transfer in progress, SMS messages are delivered over the SDCCH. If a TCH is allocated before a SMS message transfer initiates, the short message uses the SACCH which is associated with that particular TCH. If a TCH is allocated during a short message delivery over a SDCCH (i.e., a voice call or data transfer starts during short

[2] An element in the mobile telephone network that handles SMS operations.

message transfer), the short message transaction stops and continues on the SACCH associated with the TCH. If the voice call or data transfer ends, during short message transfer, the short message may either continue on the SACCH associated with the TCH or it may stop and continue delivery using a SDCCH. The sequence of the exchanged messages is similar to that of the voice call setup, with the difference that in the case of SMS message transfer when a traffic channel is not allocated, the SDCCH is not released after authentication, cipher and routing but it is retained, in order to deliver the short message [6].

The fact that SMS messages are being transmitted over data channels means that an active SMS enabled mobile terminal is able to send or receive a short message at any time, independent of whether or not a voice or data call is in progress, while it is possible to deliver a short message even if, due to overloaded network, it is impossible to allocate a voice channel. SMS also guarantees delivery of the message by the network. If the recipient's device is out of range or turned off, or in case that any other failures are identified, the message is stored at the SMSC, until recipient's headset becomes available.

The alert notification system was developed to offer sophisticated end-user services and a medium of immediate feedback to patients and clinicians. The SMS gateway, developed for the REACTION notification system, is a middleware application that accepts requests on a Transmission Control Protocol (TCP) port. The gateway was developed as an external module to REACTION's middleware with the intention to disengage the two and run them on separate boxes, if so required. To this end, the module accepts XML-based requests from the rule engine, instead of using a language specific Application Programming Interface (API).

The SMS routing gateway is a multi-threaded server. The XML-based protocol that was adopted for communication allows any number of clients to interact with the gateway. Each client is responsible for obtaining credits for the gateway, which define the amount of SMS messages the client may send. As stated above, the main communication medium will be text mobile messaging service delivered to personal mobile phones in order also to address the patient confidentiality matters.

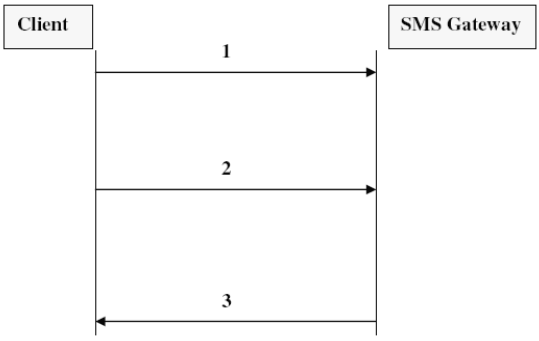

Fig. 2. Client/Server communication on SMS Gateway

Fig 2 illustrates the interaction between the gateway server and a client as a 3-stage process: 1) the client opens a TCP/IP socket connection with the gateway, 2) the client sends through the socket, a request in XML format, and 3) the gateway sends and XML-based response to the client.

4.2 Reading Action XML and Sending Sms

Exactly one message text can be delivered to an arbitrary number of GSM recipients per Hypertext Transfer Protocol (HTTP) request. Elements XML, REQUEST and REACTIONUSER are mandatory in every request. The [request-body] depends on the value of element REQUEST. In order for the SMS gateway to process a request it must first authenticate the client that submits it. The credentials of the client consist of a *username* and a *password* that are issued for every valid client of the gateway. The credentials are part of the REACTION request, enclosed element REACTIONUSER, in child-elements USERNAME and PASSWORD. The *XML elements* to be used are:

- **XML** (mandatory; XML Document Root)
- **REQUEST** (mandatory; transaction type)
- **REACTIONUSER**
  - **USERNAME** (mandatory; username of REACTION account)
  - **PASSWORD** (mandatory; password of REACTION account)
- **SUBJECT** (optional; desired originator text "REACTION")
- **RECIPIENTS** (mandatory; list of one or several REACTIONUSERS phone number to receive the SMS message)
- **PHONE** (recipient phone number)
- **MESSAGE** (mandatory)
  - **TEXT** (mandatory; message text, 1-160 characters in length)
- **MESSAGEID** (optional; message ID number to check status)

The request that the REACTION rule engine submits to the SMS gateway has the syntax displayed above.

```
  <?xml version="1.0" standalone="no"?>
  <!DOCTYPE XML SYSTEM
"http://gsms.REACTION.com/sms.dtd">
  <XML>
    <REQUEST>SENDMESSAGES</REQUEST>
    <REACTIONUSER>
          <USERNAME>user</USERNAME>
          <PASSWORD>pass</PASSWORD>
    </REACTIONUSER>
    <SUBJECT>REACTION</SUBJECT>          [request-body]
    <RECIPIENTS>
          <PHONE>4469XX123456</PHONE>
          <PHONE>3069YY654321</PHONE>
    </RECIPIENTS>
    <MESSAGE>
          <TEXT> Demo REACTION readings-</TEXT>
    </MESSAGE>
  </XML>
```

Fig. 3. REACTION request as XML based SMS message

Fig 3 describes the following: the requirements of the project has specified the need for two types of server requests, one for dispatching an SMS and one for retrieving the number of available credits for the REACTION account (latter not depicted in figure). The value of element REQUEST defines the type of instruction submitted to the gateway. The types of requests and a short description for each one are: a) SENDMESSAGES sending the message specified in the request body to a list of recipients, and b) GETCREDITS which returns the number of available credits for the REACTION account.

5 Discussion

The REACTION Alarm and Alert handling system using XSLT as rule format for configuring thresholds and actions to be taken for patients on remote monitoring programme is an efficient and constructive way to demonstrate how the rule engine is able to individualise monitoring schemes for patients.

Consequently, the Alarm notification system is, on a high level, able to react ubiquitously to change in a patient's health state and environment and invoke pre-defined activities according to some pre-programmed rules. These rules may include more complex expressions. The REACTION SMS service is a reliable way to ensure that correct receiver is notified once alarm or alerts are triggered. We suggest XSLT as basis for declarations for rule-oriented electronic health solutions where "smart spaces", interoperability and sensor data are seen as heterogeneously processed [7] or simply where adjacent notifying or actuating subsystems impose XML dependence.

Acknowledgments. This work was performed in the framework of FP7 Integrated Project REACTION (Remote Accessibility to Diabetes Management and Therapy in Operational Healthcare Networks) partially funded by the European Commission. The authors wish to express their gratitude to the members of the REACTION consortium for valuable discussions.

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