A SIP-based Medical Event Monitoring System

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Abstract— **The medical industry is transitioning to Internet-based communication as the field of telemedicine broadens to include medical event monitoring systems. A medical event monitor generates different types of messages and alerts for healthcare providers, institutions and patients. We describe how the Session Initiation Protocol (SIP), a signaling protocol for Internet conferencing, telephony, presence, event notification and instant messaging, can be used to create a medical event monitoring system. SIP can work on a variety of devices; its adoption as the protocol of choice for third generation wireless networks allows for a robust and scalable environment that can easily extend across institutions. First, we describe the basics of SIP and how it can be used for event notifications. Secondly, we describe the use of Medical Logic Modules (MLMs) in a clinical event monitoring system and we propose a SIP medical event monitoring system that can combine the use of MLMs, such as the Arden Syntax, with SIP event notification. We also propose an alternate method of event notification with the use of XML filters to deliver only relevant notifications. Finally, we discuss the different types of devices and wireless protocols that can be incorporated within the system, creating an integrated architecture.**

I. INTRODUCTION

Event notification systems are being used increasingly in many different disciplines. There are various uses for event notification systems in medicine, such as in patient monitoring systems both within a hospital and remotely, doctor-to-doctor communication, monitoring drug interactions when a doctor prescribes different medications, reminders of appointments or medications to be taken, etc. Recently, the Internet is being used in a larger scale to establish communication between doctors and patients.

We propose creating a medical event monitoring system using the Session Initiation Protocol (SIP) [1], a signaling protocol used for establishing, modifying and terminating sessions with one or more participants on the Internet. SIP has gained momentum in IP telephony as the protocol of choice and has also been accepted as the underlying signaling protocol for third generation wireless networks (3GPP). Additionally, SIP supports SUBSCRIBE and NOTIFY methods as used in event notification systems [2]. Thus, we consider SIP to be the suitable choice for our medical event notification framework.

Below we discuss how SIP is used in medical event monitoring systems. In section II, we give an overview of SIP and its use in event notification systems. We then propose a SIP medical event monitoring system in Section III which can use Medical Logic Modules, such as the Arden Syntax [3] or XML documents [4] in order to filter specific event notifications. Finally, in Section IV, we present an integrated architecture

of various devices and protocols that can be part of the SIP event notification system.

II. OVERVIEW OF SIP

SIP is part of the IETF standards process; it is similar in syntax to other Internet protocols such as SMTP (Simple Mail Transfer Protocol) used for e-mail and HTTP (Hypertext Transfer Protocol) used for the World Wide Web. It is a text-based protocol that is used to manage sessions established on the Internet. These sessions can be simple two-way telephone calls or collaborative multi-media conference sessions. Once the session has been set up using SIP, the audio and video packets are transported using RTP (Real-time Transport Protocol). The underlying transport of SIP messages can either be in UDP, TCP or Stream Control Transmission Protocol (SCTP). Within a multimedia conference, the body of a SIP message often contains a session description which enumerates the media streams to be used for the session. However, as we describe below, the message body can contain any other type of information which is relevant to the current use of SIP.

SIP users are identified with either SIP URLs, such as sip:alice@example.com or by E.164 telephone numbers such as tel:+1-212-556-4566 [5]. There are two main components within SIP: the user agent and the network (proxy, redirect or registration) server. A caller's user agent initiates a call by sending a SIP INVITE message to the local outbound proxy or a SIP server in the destination domain. The SIP URL is independent of the current IP address of the communications devices owned by the user. A user or device creates a binding from its "generic" address-of-record such as alice@example.com to its current network location, such as alice17@pc42.accounting.nyc.example.com. By periodically sending SIP REGISTER requests to the home SIP server, a binding is created with the Contact header representing the current network address the user is available in.

SIP has also been extended to generate event notifications and instant messages [6]. Users subscribe to an event with the SUBSCRIBE method and receive notifications via NOTIFY. This event notification facility is used for events that occur during telephone calls, as well as presence notification. This can also be used for generic event notification systems. As shown in Figure 1, a user agent client sends a SUBSCRIBE request to the appropriate server. This request contains an "Event" header indicating the type of event the user is subscribing to. In the case where a user is interested in a range of events,
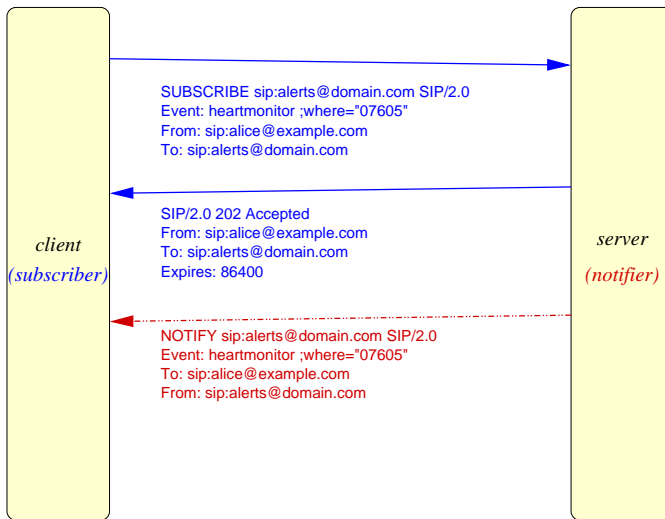
SUBSCRIBE sip:alerts@domain.com SIP/2.0
Event: heartmonitor ;where="07605"
From: sip:alice@example.com
To: sip:alerts@domain.com

SIP/2.0 202 Accepted
From: sip:alice@example.com
To: sip:alerts@domain.com
Expires: 86400

NOTIFY sip:alerts@domain.com SIP/2.0
Event: heartmonitor ;where="07605"
To: sip:alice@example.com
From: sip:alerts@domain.com

Fig. 1.   Protocol exchanges for event alerting

it sends multiple SUBSCRIBE messages. The request's "Expires" header specifies the duration of the subscription. SUBSCRIBE messages can be refreshed whenever the subscription has expired. If a subscriber wants to unsubscribe, it can send a SUBSCRIBE message with an expiration time of zero. Once the server receives the subscription, it adds the subscriber to the appropriate event list upon approval of the subscription and then generates NOTIFY requests to the subscriber when an alert occurs. When a device is either no longer interested or capable of receiving alerts, subscriptions time out in order to prevent the devices from consuming network resources.

Another feature of SIP is that it supports a method, which is used to control appliances connected to the computer. This capability allows SIP to control electric devices remotely. Thus, when issuing a NOTIFY, remote procedure calls can be made to the suscriber's system which automatically invokes a function on a connected device.

Doctor-patient confidentiality is a crucial area in medicine. Thus, authentication and authorization are necessary in a medical event monitoring system for both subscriptions and notifications. Subscriptions need to be authenticated for distribution of events and also to prevent a doctor or patient from subscribing multiple times or redirecting the subscription of their neighbor either accidentally or intentionally.

SIP can use existing security mechanisms like HTTP Digest or transport layer security (TLS). HTTP Digest mechanism is used for authentication using a shared password, but it does not provide encryption of the messages. TLS is preferred for secure and encrypted SIP communication.

III. SIP-BASED MEDICAL EVENT MONITORING SYSTEM

There are many possible ways of creating event notification applications. Within the medical field, SIP can be used for reliable delivery of an event in case of an emergency or for alerting doctors. There are various ways an event notification

system can be built using SIP. One is by using pre-set Medical Logic Modules, described in section A, within the NOTIFY message body. The other is by using XML-formatted messages.

A. Medical Logic Modules

Medical Logic Modules (MLMs) encode medical knowledge which are used in decision-support systems. However, since one medical institution will never define a complete medical knowledge base, sharing across institutions is necessary. Sharing knowledge gives way to many obstacles. Medical institutions typically do not share the same decision support systems. Thus, when sharing knowledge across institutions, coordinating local vocabularies and translating the logic for automation is a strenuous process.

The Arden Syntax is a Medical Logic Module that has been developed for the task of sharing medical knowledge bases across many institutions [3]. Its main focus is on knowledge used in decision support systems that can provide therapeutic suggestions and alerts. It is compiled and then run automatically to generate advice where and when it is needed. Although there are other types of MLMs, such as GLIF [7], we focus on the Arden Syntax for the examples in this paper.

MLMs are text files that are arranged into slots where each slot contains either free text, a coded term or structured data. Generally, there are three slots: maintenance, library and knowledge, as seen in Figure 2 . The maintenance slot contains management information such as title, filename, author, etc. The library slot is more of a commenting section where the purpose of the MLM is described. Preferably, the Unified Medical Language System (UMLS) [8], which is a dictionary of medical terms, is used in this slot so that a variety of institutions can interpret the purpose of the MLM correctly. The third category which is the main logic of the MLM is the knowledge category. In this category, there are various ways of representing or querying knowledge. There are five different subsections within this category. The type section describes the way the MLM is to be used. The data section assigns local variables, which can be lengthy database queries, to be used by the MLM. The database query is used to obtain patient data and act upon it in a certain way. The evoke slot contains the conditions under which the MLM becomes active. For instance, as seen in Figure 2, when an absolute neutrophile count (ANC) is stored, the MLM becomes active. The logic section consists of the actual rule or medical condition to test for once the MLM is active and the action section describes what is to be done when the condition is true.

Thus, by using the Arden Syntax, an automated clinical event monitoring system can be designed where an institution can use this within its own area for monitoring clinical data or across institutions. If a remote institution wants to be alerted of some specific data within another hospital's database, it can construct an MLM containing a database query and the action it wants performed whenever the data of that query is equal to some specific value. In this way, medical knowledge is shared across wider boundaries. References [9] and [10]

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maintenance:
    title:Agranulocytosis and
        Trimethoprim/Sulfamethoxazole;
    filename:anctms;
    version:2.00;
    institution:Zoo University;
    author:Dr. Bonzo;
    specialist:;
    date:7/20/1989, 7/23/1990;
    validation:testing;
library:
    purpose:Display the Arden Syntax;
    keywords:
        granulocytopenia; agranulocytosis;  trimethoprim; sulfamethoxazole;
    citations:
        1.  Anti-infective drug use in
        relation to the risk of agranulocytosis and aplastic
        anemia.... Arch Int Med  1989;149(5):1036-40.
    links:
        MeSH agranulocytosis/ci and   sulfamethoxazole/ae;
knowledge:
    type:data-driven;
    data:
        /* neutrophile count in #/mm3 */
        anc := read last 2 from ({query
            for ANC} where it occurred
            within the past 1 week);
        pt_taking_tms := read exist
            {query for TMS order};
    evoke:on storage of {ANC};
    logic:
        if pt_taking_tms      /*1*/
        and last anc < 1000
        and decrease of anc > 0 then
            conclude true
        else
            conclude false;
    action:store "Caution:  The patient's
        relative granulocytopenia may be
        exacerbated by
        trimethoprim/sulfamethoxazole.";
```

Fig. 2.   Sample of an Arden Syntax

describe various ways the Arden Syntax is used or extended for clinical event monitoring systems.

In Ref. [9] a user can subscribe to an Arden Syntax rule that has already been implemented within the server. Thus, the participants within the monitoring system are aware of the Arden Syntax rules within each institution. When SIP is used for messaging, a SIP SUBSCRIBE is sent with the message body containing the name of the rule that the subscriber is subscribing to. The server executes this rule within its system and notifies the subscriber whenever that particular rule becomes true. Thus, a doctor enters the Arden Syntax rules he is interested in for a particular patient, via a SIP user agent application, and subscribes to those particular events.

Another way that this may be implemented is by dynamically adding Arden Syntax rules within a server's knowledge base for monitoring purposes. In this example, a subscriber inserts the rule itself within the SUBSCRIBE message body. The server receives the SUBSCRIBE message and extracts the message body, compiles the syntax and then executes the logic within the syntax. The server will monitor the database and whenever the syntax becomes true, it will invoke the action specified within the rule via a SIP NOTIFY message. In this scenario, the rule is also being used as a filter. The subscriber is subscribing to specific events within the server and indicating the data it is interested in and the type of notification needed.

This is not the usual way the Arden syntax is implemented, even though it enhances the monitoring system's capabilities. Since institutions each have their own custom databases, adding a dynamic syntax rule may result in incompatibility with the database that is being queried to. Unless the subscriber knows the exact query language of the remote server's database, this will not work. One way that the Arden Syntax has worked around this problem is by creating a generic querying language that may be used in the data section of the MLM. This way, the language can be read manually by an operator and translated to the specific database query of that institution's database. An obvious drawback to this is that the monitoring system will not be fully automated. As we describe in the next section, one solution to this problem would be to use XML messages within the SIP body.

B. XML Messages

XML, short for Extensible Markup Language, provides greater flexible and adaptable information identification. It is a "metalanguage", which is a language used for describing other languages and thus allows for the design of a customized markup language for many different types of uses. It has become very popular in web-related programming since representing structured data over the web has become much simpler with the use of XML. XML is often used in conjunction with XML schemas [11]. An XML schema is an XML language that describes and constrains the content of XML documents.

Within the context of SIP event notifications, XML's feasibility for automation makes it a good choice for interoperability within many different types of institutional systems. In this design, the XML message is used for representing a database query, a filter for events subscribed to and specification of alerting methods, as well as performing remote procedure calls. Below we describe a design using the different components of XML within a SIP event monitoring system.

Similar to the Arden Sytnax's database query section, XQL (XML Query Language) [12] may be used to query a remote database. XQL is a general-purpose query language that is being standardized within the W3C. Since the medical field often has a problem of interoperability due to different database and software systems residing in each institution, XQL provides a clean way of automating database querying within institutions, assuming a common XML schema is shared. Thus, the XQL document is processed automatically within the notification server by interpreting the XQL document and translating it to its own database query language.

XML may also be used for filtering specific events as well as requesting particular alert methods by the notification server. Filtering events using XML is now being discussed within the IETF [13]. The "Events" header in a SIP SUBSCRIBE message specifies an event package to subscribe to, but does not filter out particular events. Thus, in the case where a user may want to subscribe to only specific events, an XML document can be used to filter out the events requested. Using XML schemas can further automate the subscription process. The schema describes the events and each of their
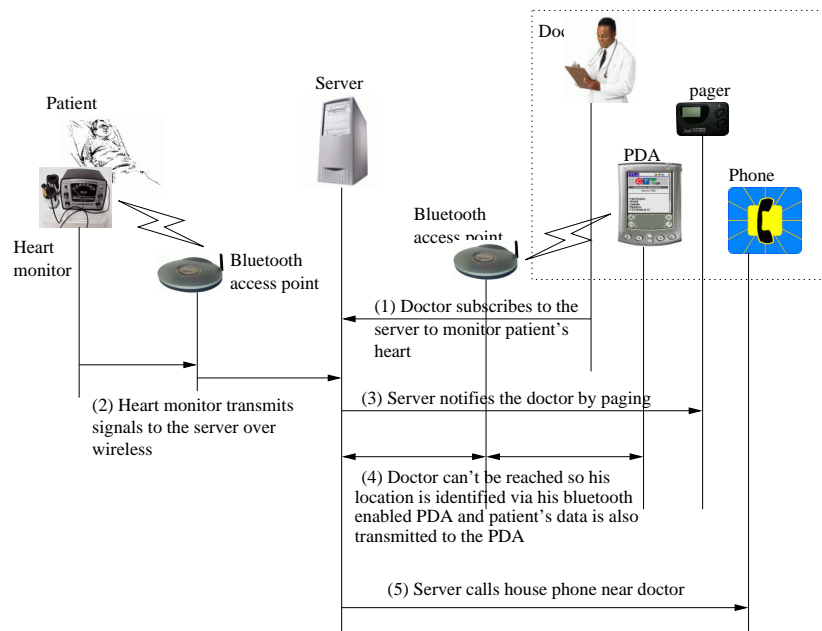
Fig. 3. Integrated architecture of SIP medical event monitoring system

parameters and data types, as well as specifies various alerting methods offered by the notification server. Therefore, when a user subscribes to the event, the schema is processed generating a graphical user interface for the subscriber to input his information creating a more user-friendly application. Once the information is entered, an XML message is created representing this information and sent to the notification server inside the SIP SUBSCRIBE message.

In addition to using XML for subscription, it can also be used to enhance notification via remote procedure calls. SOAP (Simple Object Access Protocol) [14] is an XML-based remote procedure calling mechanism. It facilitates a program running in one platform to communicate with a program within the same or remote platform. It is often used with HTTP, but can also be used with any other application transport protocol such as SMTP or in this case SIP. The fact that SOAP is interoperable between different platforms, makes it very convenient to use in the medical domain. Thus, when the notification server sends a NOTIFY, it embeds a SOAP message within the body that represents a call to a function on the remote system. The SOAP message is then processed and the function call is executed accordingly.

We are currently implementing a prototype version of a generic SIP-based event notification system. The Columbia SIP user agent, sipc, and the SIP proxy server, sipd, are being extended to handle event notifications using XML messages for filters and remote procedure calls [15]. With the use of XML schemas to describe the events and their parameters, this implementation can be used for wide range of event notification systems.

IV. OVERALL ARCHITECTURE

The SIP medical event monitoring system, when combined with various devices and protocols, constitutes an integrated and robust architecture. The subscription can contain various methods of alerts in the XML filter. Thus, when a doctor subscribes to the event monitoring system, he can be notified in many different ways such as via phone calls, instant messages, pages, or alarms. Since device control is also possible, a doctor may want to invoke a certain device automatically when notified.

Currently, the use of Bluetooth is being considered in the medical industry [16]. Bluetooth [17] is a specification that uses low-power radio signals to link phones and computers wirelessly. Bluetooth technology transmits these signals over a relatively short distance, typically no more than 30 feet. Companies such as Colorado MEDtech and Code Blue Communications Inc. [18], are developing bluetooth-enabled medical devices. These devices provide mobile access to information and medical data acquisition. It also enables devices to communicate with each other wirelessly. Bluetooth can also be used for location-based services such as detecting the doctor's whereabouts or for establishing ubiquitous systems in the hospital environment. Thus, a doctor can be alerted any time and any way he chooses according to his subscription.

An example of the architecture utilizing these different components is illustrated in Figure 3. Here, a doctor wants to remotely monitor a patient in another hospital. He subscribes to the SIP event monitoring server by indicating the events he wants to be alerted for, such as when the patient's heart monitor reads a certain value. He also indicates various methods of alerts in order of priority. For example he is first paged.

Then if he doesn't answer the page, his location is tracked within the hospital via a Bluetooth access point detecting the Bluetooth-enabled PDA he is carrying. Once his whereabouts have been detected, this information is transferred to the SIP server and a house phone nearest to that location is alerted. The doctor may also have requested a remote procedure call when the event occurs. When the NOTIFY is sent, not only is he alerted but data is acquired from the patient's heart monitor and sent to the doctor's PDA. Thus, using SIP for notification and Bluetooth for determining the location of a mobile doctor, creates a flexible and robust architecture in the hospital.

V. CONCLUSION

Medical event monitoring systems on the Internet are becoming prevalent. However, interoperability across institutional boundaries is often an issue when designing such a system. SIP provides a flexible and robust event notification architecture which not only addresses this problem, but uses existing medical technology as well as providing enhancements to it.

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