AN AGENT-BASED ALERT DISTRIBUTION SYSTEM FOR INTELLIGENT HEALTHCARE MONITORING

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ABSTRACT

AN AGENT-BASED ALERT DISTRIBUTION SYSTEM FOR
INTELLIGENT HEALTHCARE MONITORING

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With the high-level developments in the information technologies, there is a big movement in the e-health area both to give better healthcare services and to reduce cost. Monitoring the patients from their home location is one of the important branches of e-health with the aging societies. In this work, an agent-based alert system is introduced which analyzes the alert message requests and sends the alert messages within the appropriate structure and communication channel to the related healthcare user. A guideline execution system produces the alert requests based on sensor data and informs the alert agents.

A multi-agent platform is developed which proactively sends the alert messages on behalf of the system with acknowledgement and message routing abilities. The multi-agent platform has patient alert agents for each patient in the system. A rule engine is cooperated with agents for the analysis of the alert message requests to bind these requests with the healthcare user specifications. E-mail messaging, SMS and MSN Instant messaging are used to reach the healthcare

users. Additionally, web-based user interfaces are developed for healthcare users to manage the alert system for intelligent healthcare monitoring by specifying alert message receiving rules, personal and contact information, and some more additional options.

The work presented in this thesis is realized as a part of the SAPHIRE project funded by the European Commission.

Keywords: e-Health, Medical Alert Systems, Intelligent Agents, Rules

ÖZ

AKILLI SAĞLIK TAKİBİ İÇİN
AJAN-TABANLI UYARI DAĞITIM SİSTEMİ

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Yüksek Lisans, Bilgisayar Mühendisliği Bölümü
Tez Yönetici : Prof. Dr. Asuman Doğaç

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Bilgi teknolojilerinde yaşanan ileri düzey gelişmelerle beraber, e-Sağlık alanı da hem daha iyi sağlık hizmeti vermek için hem de sektördeki masrafları azaltmak doğrultusunda bir yönelim göstermektedir. Hastaları kendi evlerinde takip etmek, yaşlanan toplumlarla beraber e-Sağlık sektörünün önemli bir dalını oluşturmaktadır. Yapılan bu çalışmada, akıllı sağlık takibi için bir ajan-tabanlı uyarı sistemi geliştirilmiştir. Bu sistem, alınan uyarı mesajı isteklerini analiz ettikten sonra uyarı mesajını gereken yapıda oluşturup ilgili sağlık sektörü kullanıcısına uygun iletişim kanalı yoluyla gönderir. Kılavuz yürütme sistemi, alıcı verilerine dayalı uyarı mesajı isteklerini üretir ve uyarı ajanını bilgilendirir.

Alındı bildirimi ve mesaj yönlendirme özelliklerine sahip, sistem adına uyarı mesajları gönderen ve her zaman aktif olan bir çoklu-ajan platformu geliştirilmiştir. Çoklu-ajan platformu sistemdeki her bir hasta için bir hasta uyarı ajanına sahiptir. Ayrıca bir kural motoru, ajanlarla sisteme gelen uyarı mesajı isteklerini analiz etmek amacıyla koordine edilmiştir. Bu yapı gelen uyarı mesajı

istekleriyle, kullanıcı tarafından belirtilen özellikleri birbirine bağlar. E-posta mesajlaşması, SMS ve MSN anında mesajlaşmaları, sağlık sektörü kullanıcılarına ulaşmak için kullanılacaktır. Bunlara ilaveten, sağlık sektörü kullanıcılarının akıllı sağlık takibi için ajan-tabanlı uyarı sistemini yönetmeleri için, uyarı mesajı alma kurallarını belirtmek, kişisel ve iletişim bilgilerini tanımlamak ve diğer ek özellikler için, web-tabanlı kullanıcı arayüzleri geliştirilmiştir.

Bu tez kapsamında sunulan çalışma, Avrupa Komisyonu tarafından desteklenen SAPHIRE projesinin bir parçası olarak gerçekleştirilmiştir.

Anahtar Kelimeler: e-Sağlık, Medikal Uyarı Sistemleri, Akıllı Ajanlar, Kurallar

To My Family

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CHAPTER I

INTRODUCTION

With the advancements in the information technologies, the efficiency and response times get better in the healthcare domain. It is known that the healthcare domain is a complex domain with huge bundle of information, many standards, procedures and workflows; digitization of all these mass set of data, information and knowledge will certainly improve the healthcare domain from various aspects. Additionally, the society of human-being is getting older and they face with various illnesses in their long lives. This directly effects the healthcare operations and costs with the changing societies. The remote healthcare monitoring which is mainly executed at the home of patient is getting popular both to offer better healthcare services and to reduce costs. This remote healthcare monitoring system watches the patient with intelligent technologies such as sensors, clinical guidelines and agents, and it co-operates with the main healthcare institutes to take the required action for the patient.

This thesis aims to develop an agent-based alert distribution component within the scope of the Saphire project [18]. The Saphire project aims to monitor the vulnerable patients by specific guidelines which are fed data through sensor networks. The sensors which are gently located on the patient, measure the intended medical values; such as blood pressure, glucose level, heart rate or others, and the clinical guidelines remain in a proactive state for any abnormal case with the provided values from sensor networks. If some value goes beyond the limits, the specified clinical guideline is executed automatically by the help of agents and the healthcare stakeholders, who can be doctors, nurses or patient relatives are informed with auto-generated and transmitted medical alert messages by the Saphire Alert System. As it will be detailed in the proceeding sections, Saphire Alert System is based on the multi-agent platform and the alert decisions are mainly structured through a rule-based system.

The thesis is organized as follows: in Section 2, the related work is presented. In Section 3, the Saphire project is introduced. In section 4, the requirements and the components of the Saphire Alert System are described. In this part the details of the alert system components are provided with the general specifications, needs and requirements of the Saphire Alert System. Finally, Section 5 presents the conclusion for Saphire Alert System.

CHAPTER II

RELATED WORK

Various technologies are utilized while developing the Saphire Alert System. Agent technology is one of them where an agent is a software entity which can carry out information-related tasks without ongoing human supervision. Below it can be found another definition [21];

“Intelligent agents are software entities that carry out some set of operations on behalf of a user or another program with some degree of independence or autonomy, and in so doing, employ some knowledge or representation of the user's goals or desires."

Software agents have some fundamental characteristics which are autonomy (system acts without human intervention), social ability (collaboration among agents), reactivity (perceive the environment and respond according to), proactivity (exhibit goal-directed behavior by taking the initiative). Multi-agent systems are the cooperative working environment where the single agents come together to solve the complex problems. While agents are structuring for mutli-agent platforms, interoperability issue raises up for both communication between agents and collaborative working. Agent Communication Language (ACL) [23] has been produced for the communication between the agents. ACL mainly uses ontologies for messages those are exchanged between the agents. The Foundation for Intelligent Physical Agents (FIPA) [24] produced software standards for heterogeneous and interacting agents and agent-based systems. Some software agent platforms are developed which are FIPA complaint. JADE [1] is one of them, which is utilized in the Saphire Alert System. JADE is developed by Telecom Italia Lab and it is a FIPA compliant agent development environment. It mainly relies on two assumptions of FIPA; it is only an enabler

and external behavior of system components are specified, not the internal architectures of agents. In the Figure 1, it can be seen the main FIPA reference model of an agent platform.

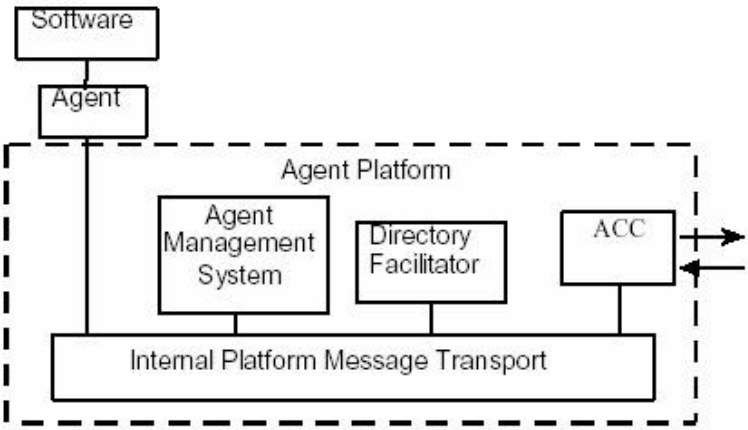


Figure 1 FIPA Reference Model of an Agent Platform

Another technology which is utilized in this work is the JESS Rule Engine [2]. Java Expert System Shell (JESS) is an expert system shell and scripting language written entirely in Sun Microsystems's Java language [22]. JESS supports the development of rule-based expert systems which can be combined with JAVA language. To add the decision making capabilities to the software agents, JESS can be integrated with JADE as the inference engine.

There are also some implementations on the domain which are structured for the purpose of medical alerting. However Saphire Alert System has some advantages over them by supporting various communication channels, acknowledgement ability, routing mechanism, user-friendly interfaces and others. The other existing systems mainly use mobile phones and pagers for communication. However, pagers are quite old technologies and with the high advances in the Internet platform, this is not adequate for seamless integration with the existing and future healthcare information systems. In particular, healthcare applications must respond actively and very timely to patients' needs, which can be very critical.

In the research of [12], it is mainly focused on developing a mobile alert system for better conditions of patients with chronic diseases. The main philosophy is similar where the health conditions of the patients are monitored and the alert messages are delivered to doctors if an emergency situation is occurred. The patients can set up some personal alerts for the conditions they specified. In this study, the main conceptual and architectural designs are presented whereas the technical details of the system are missing. Within the study of [13] the agents are utilized to monitor the vulnerable patients and send alarms automatically whenever a need arises. The developed system is deployed and used in a hospital in Barcelona, Spain. In this system, it is structured a multi-agent platform with doctor agents, patient agents and database wrapper agents. In addition to all, it is structured a data analyzer agent for data mining, knowledge discovery and machine learning techniques. For the alarm management, it is developed a complexity criteria (personal characteristics of the patient, special medical problems, therapeutic strategies, family issues) to specify the alarm message aspects. In this system, it is supported mobile communication ways (SMSs, e-mails, mobile phones) for the alarm messages.

In the study [14], it is developed a healthcare alert management system to handle the alert messages. The proposed system is built over the alert message requirements where the alert monitor matches the medical staff and the mobile devices they own. The acknowledgement and routing mechanisms are also supported by the proposed approach. The work of [15] mainly focuses on the clinical notification system by multiple communication channels, third party mappings (algorithms) from message to recipient and/or channel of delivery and escalation mechanisms. For this clinical notification system, it is mainly used JAVA with CORBA objects. Another real-time clinical alert system is developed for the Intensive Care Unit (ICU) [16] which runs the alert algorithms stored in database with sixty-three ICU parameters. The algorithms are basically structured over rules and by the developed rule editor; the users can specify their

own algorithms. If a condition is detected which is specified by the algorithms, the system sends an alert message by mobile phones or pagers.

The system of [17] works with healthcare chain workflow management under urgent constraints. Within this system, each alert is associated with healthcare tasks and also some parameters are specified which are used for urgency requirements and routing. The developed system also support the acknowledgements which are sought for alert messages and after the acknowledgement deadline, the alert may be re-routed with the necessary requirements of the alert message. Web Services are used for the integration of the developed alert management system with whole healthcare system.

CHAPTER III

SAPHIRE PROJECT

The medical practitioners at all levels are becoming more overloaded as the aging population of Europe increases. The health services of the EU can claim considerable credit for the decline in mortality over the last thirty years. However this success, particularly the fall in mortality rates among older people, has increased the demand for healthcare. Furthermore, there are discrepancies in health status between the old and new (CEE) member states due to health system failures in the latter. For example, about a quarter of the difference in mortality rates between East and West Europe has been attributed to inadequacies in healthcare. On the other hand information technology, combined with recent advances in networking, mobile communications and wireless medical sensor technologies offers a great potential to support healthcare professionals and to deliver healthcare services at a distance hence providing the opportunities to improve healthcare both in the old and new (CEE) member states.

The Saphire project [18] develops an intelligent healthcare monitoring and decision support system to address this problem in the enlarged EU. In the Saphire project, the patient monitoring is achieved by using agent technology where the "agent behaviour" will be supported by intelligent decision support systems based on clinical practice guidelines. In Saphire system, patient history stored in medical information systems is accessed through semantically enriched Web Services to tackle the interoperability problem. In this way, not only the observations received from wireless medical sensors but also the patient medical history is used in the reasoning process.

Clinical Decision Support Systems (CDSS) broadly refer to providing clinicians or patients with clinical knowledge and patient-related information, intelligently

filtered and processed to enhance patient care. Recently, there has been an explosion in basic and clinical research on disease pathophysiology and treatment. Coupled with increased demands on healthcare delivery systems, this rapid growth has made the practice of medicine increasingly complex. The healthcare community response to this growing complexity has been to develop clinical practice guidelines to simplify and improve healthcare delivery. As an example, the National Guideline Clearinghouse™ [19] provides a comprehensive database of evidence-based clinical practice guidelines and related documents. Despite the widespread publication of clinical standards and practice guidelines, however, healthcare professionals have difficulties in understanding and applying these guidelines in the clinical care setting. This necessitates computerized decision support systems automating clinical guidelines to support the health professionals. One of the major challenges in developing computerized decision support systems is accessing the many disparate data sources needed to retrieve patient-specific information.

In the Saphire project, the clinical decision support system to be incorporated into the system as an agent behaviour, access patient medical history stored in medical information systems through semantically enriched Web Services to tackle the interoperability problem. In this way, not only the observations received as patient's physiological signs data but also the patient medical history is used in the reasoning process. This is an essential component, because in clinical guidelines, the physiological signs received from wireless medical sensors, the patient care plan and medical history (such as previous diagnosis, medication list, allergy/adverse drug reactions) all affect the clinical path to be followed. More specifically the interoperability problem that needs to be addressed to develop an effective intelligent healthcare monitoring tool is as follows: the data coming from the wireless medical sensors are either in proprietary format (for example, for electrocardiogram data, Philips' XML ECG Data Format) or when it conforms to a standard, this still does not solve the interoperability problem since there are very many standards. When it is wanted to integrate this data with electronic healthcare records, the problem gets more

complex since hospital information systems are also mostly proprietary and when they conform to an interface standard, there are again very many standards and thus the standards do not achieve the aimed interoperability. Furthermore, interoperability of data coming from various wireless medical sensors is also essential to infer information by combining data coming from various sensors.

The interoperability problem in the Saphire project is addressed by exposing the data coming from sensors as well as the data stored in medical information systems as semantically enriched Web Services; that is, it is annotated both the functionality and the messages of these Web services through standard based ontologies. In this way, the "functional interoperability" which allows different platforms to exchange information will be solved by making use of Web Services and the "semantic interoperability" is handled by using ontologies based on medical standards. Using ontologies lets different medical platforms to interoperate at the semantic level, since we can define mappings and translations between ontologies. Such an interoperability platform will then allow developing the intelligent decision support system for monitoring the healthcare process.

The Saphire system continuously monitors the patients through dedicated agents and supports the healthcare professionals through intelligent decision support system it develops that will produce and send alerts to the related people.

Creating such an information infrastructure requires safeguards to maintain security and privacy of patient data. Patient identification and medical records can not be disclosed indiscriminately and different healthcare providers have different access rights. The Saphire project proposes comprehensive security and privacy mechanisms to complement the infrastructure proposed. The Saphire project is built upon the results of a European commission funded project, IST-1-002103 Artemis [20], which is developing a semantic web service-based P2P Infrastructure for the Interoperability of Medical Information Systems. Artemis project enables the healthcare institutes to exchange Electronic Healthcare

Records in interoperable manner through semantically enriched Web Services and semantic mediation. The Saphire project exploits these results by integrating the patient data collected through wireless medical sensor devices with the hospital information systems. This infrastructure constitutes the interoperability base for the intelligent healthcare monitoring system.

Saphire project enables healthcare professionals to study and monitor many pre-hospital, in hospital and ambulatory patients any time with a high accuracy with the help of the intelligent decision support system. From the point of view the patients, Saphire advantages are getting better treatment and the possibility to be hospitalized at home. Through its homecare application, Saphire project enhances quality of life for elders, including the ability to "age in place", that is, to stay home rather than move to institutions; improve healthcare through prevention and early detection of disease; lower soaring healthcare costs; and unburden family members and other care givers.

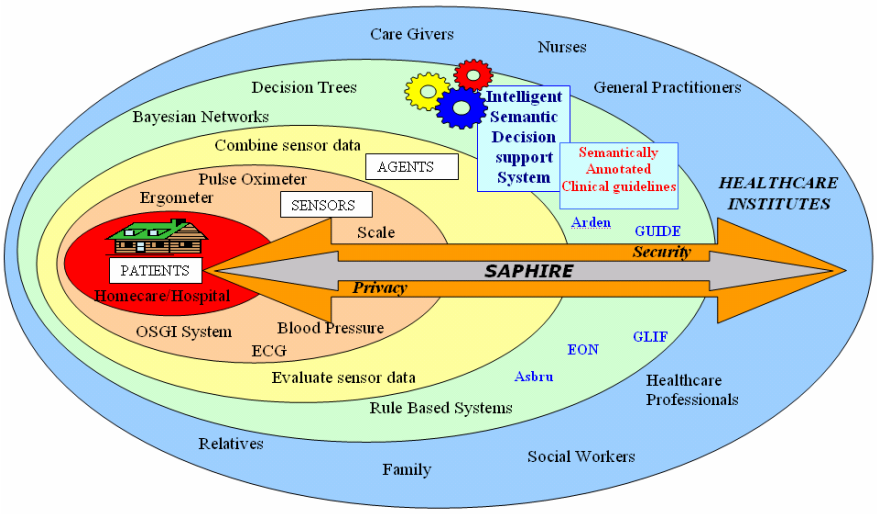


Figure 2 Overall vision of the SAPHIRE Project

In the Figure 2, the overall structure of the Saphire project can be seen with all its phases. As a result of the Saphire project the following components will be available besides the alert component;

- **The Intelligent Semantic based Clinical Decision support system** is the component of the Saphire system for continuously monitoring the patients in order to provide healthcare professionals and/or patient families with clinical knowledge and patient-related information, intelligently filtered or presented at appropriate times, to enhance patient care. The intelligent healthcare monitoring network is composed of dedicated agents monitoring the status of each patient. Clinical guidelines accessing sensor data and medical records are loaded as behaviours to these agents.
- **A User Friendly tool (GUI)** is needed to describe various medical processes to be followed realizing semantic based clinical guideline implementation: Decision processes (workflows) are designed based on available clinical practice guidelines and loaded to the agents as agent behaviours.
- In the Saphire project an **Interoperability Platform** for Wireless medical sensor Networks based on Web Services are developed. The data coming from sensors as well as the data stored in medical information systems are exposed as semantically enriched Web services. Both the functionality and the messages of these Web Services are annotated through standard based ontologies in order to achieve functional and semantic interoperability. In this way it will be possible to integrate disparate and proprietary Medical Information systems and data coming from sensor devices. This interoperability platform is used in two ways: first it enables the development of the intelligent decision support system for monitoring the healthcare process and just-in-time delivery of alerts and recommendations, secondly it enables the integration of sensor data with EHRs stored in medical information systems.
- Saphire Project also provides comprehensive **Security and Privacy Mechanisms** to complement the infrastructure proposed. Security and privacy mechanisms are designed specifically for sensor data and network protocols considering the hardware and energy constraints of the sensor devices. Also security and privacy mechanisms for Web Services are implemented and these mechanisms are integrated to the Intelligent Semantic Based Clinical Decision Support System that is developed.

- In the Saphire project a **Sensor network** is established including the off-the-shelf sensor devices for measuring Oxygen saturation, Blood pressure, Respiratory rate, ECG, pulse oximeter, temperature and the activity level of the patient (accelerometer). This sensor network enables the "gathering" of sensor data including interfacing sensors to a/d converters, digitization, and transmission of digitized data to secondary storage and processing nodes and "refining" of sensor data including cleaning, segmentation, and separation.

The components of the Saphire system and how they interact are presented in Figure 3.

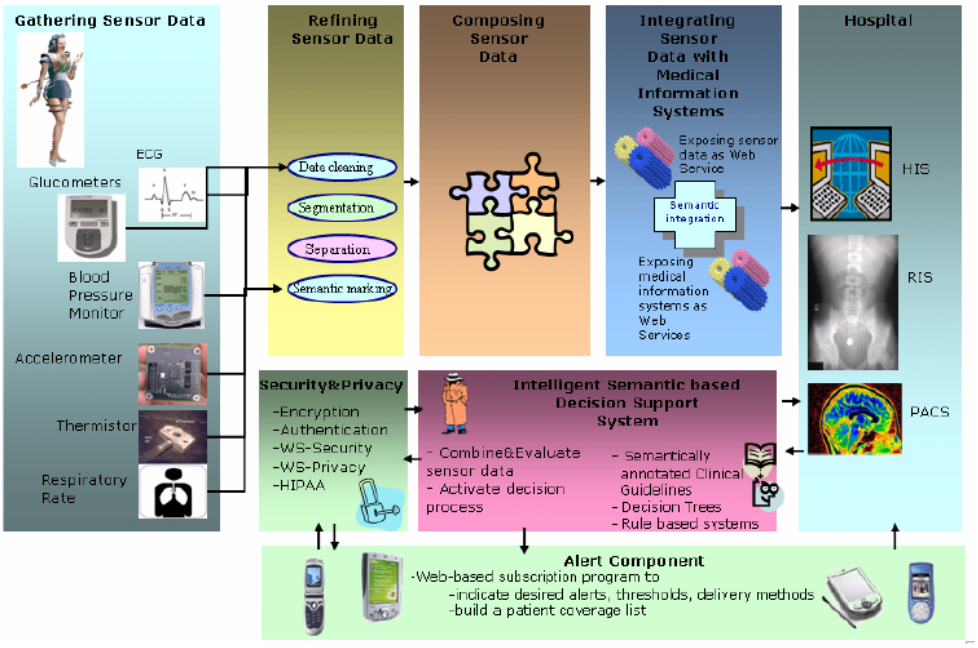


Figure 3 Components of the SAPHIRE system and how they interact

CHAPTER IV

MEDICAL ALERT SYSTEM REQUIREMENTS & COMPONENTS

The Saphire Alert System is needed for the full functionality of the Saphire Intelligent Healthcare Monitoring System. Its main purpose is to generate reactive actions and alerts to the related people in situations requiring attention and external help. For this aim, a web-based user interface has been developed where the healthcare stakeholders have full control over the alert management. The personal and contact information can be provided to the system by this web-based user interface. The alert receiving specifications can be entered to the system by the provided interface. Additionally, assignments of patient, clinical guidelines and healthcare actors are accomplished by the help of web-based user interface.

The alert system is required to support various communication channels whose dimensions change between cost and delivery time. As the urgency level of an alert message can change, different communication channels are required to be offered. For example, urgent message can be sent through SMS since the mobile phones are one of the fastest communication methods. Additionally, urgent messages can also be sent with instant messaging service where one of the most popular one is MSN Messenger. The other channel for alert system is decided as e-mail messaging. E-mail sending is both free and fast as instant messaging. SMS, Instant messaging and e-mail messaging form the base three communication channels to reach the healthcare users in the most appropriate way. However, the security issues need to be addressed within these communication channels where the security and privacy have high importance in the healthcare domain. For this purpose, especially the e-mail messages should be encrypted before sending to the recipient and only the authorized user can decrypt the encrypted e-mail message.

Another important requirement is the handling of the alert messages within a specified time period. As previously stated three main types of communication ways are required, the healthcare user is required to have option to select the communication channel for urgency level. For instance, the doctor can select to receive the critical alert messages with SMS whereas he/she can also get the less urgent messages through e-mail. Within the scope of the general alert system requirements, the healthcare users can express their preferences about alert message receiving channels through the provided web-based user interface. These decisions are stored and executed with a rule-based approach where the details will be elaborated in the proceeding parts.

The disease type of the alert message forms another requirement which should be considered within the delivery of the alert message. The disease type also has effects over the urgency level of the alert message. The alert system should provide the ability to healthcare users to state the urgency level changes for the specified disease type. For instance, for a specific patient where an alert message is created with the disease type cardiovascular, if the doctor specified to the alert system that there should be a conversion from "Reminder" urgency level to "Important" urgency level, this conversion should be done automatically and the alert message should behave as required by the currently set urgency level. As the communication channel selection is structured over a rule-based system, the urgency level conversion is also structured over the rule-based mechanism.

In addition to these vital requirements, there are also some other requirements which have importance over general processes of the alert system. Besides the requirement of supporting various communication channels, the system should support to send the multiple alert messages after an alert-producing event. At the same time for a specific patient and guideline, the alert system should have the capability to send multiple messages whose receivers are different. After an event, the doctor can be informed with more medical-oriented information

whereas the patient relative can receive an alert message containing more generic information which does not involve any technical medical details.

The acknowledgement of the sent message is important especially for the healthcare domain where the actions are needed to be done quickly and in a reliable way. Hence, for the alert messages if the user specifies that acknowledgement is needed; the acknowledgement of the sent message is expected by the system. If the acknowledgement fails to be received, the message is routed. The routing requirement has a key role such that if the acknowledgement cannot be taken, the alert message is routed to another determined healthcare user not to cause any information leakage within the Saphire System. Over all these Saphire Alert System requirements, the logging has a key role which is inevitable for healthcare domain for future inspections for the actions over the patients. The output of the logging mechanism should be provided to the healthcare user through various methods; on-screen, printing or e-mail.

The alert system components are analyzed, designed and implemented according to the requirements which are described above. The use case diagrams are drawn for the main functionalities of the alert system. Afterwards, the main flows of the alert system use case diagrams are structured with the identified actors of the Saphire Alert System. The main user interfaces especially for the web-based user interface component are designed. The general rule formats and Saphire Alert System Database Schemas are defined whose details are given in the Section 4.2. Before going into the details with the succeeding subsections, it is better to define the Saphire Alert System Actors;

- **Healthcare Administrator:** The healthcare administrator is the super user of the Saphire Alert System. This user mainly accesses the system from the web-based user interface. The healthcare administrator manages the addition of the new healthcare actors to the system. Additionally, administrator assigns a patient with guideline to produce patient-guideline pairs for alert messages. Healthcare users are also assigned to

the patient-guideline pairs by the administrator. Finally, the Saphire Alert System enables the healthcare administrator to import external patient information from other proprietary healthcare systems by the use of Web Services. All these functionalities are accomplished by the developed Saphire Alert System Web-Based User Interface.

- **Healthcare User (Doctor, Nurse and Patient Relative):** The healthcare user can be medical doctors, nurses and patient relatives who receive alert messages from the Saphire Alert System. Healthcare users are added to the system by the administrator and they can define the ways and criteria of how the alert messages should arrive. The Saphire Alert System Web-Based User Interface enables healthcare users to manage the patient-guideline pairs; the healthcare users can define the alert message receiving rules, personal and contact details, they can also access to the logs of alert messages.
- **Alert Agent:** The alert agent actor is created automatically and is always alive when the Saphire Alert System is functioning. The alert agent is a software agent which is running in the environment of JADE [1]. These alert agent actors are prepared and run for each patient in the Saphire Alert System which is proactive for any alert messages those can be received from the main Saphire System. The responsibility of the alert agent is to analyze the received alert message with the input of the healthcare actor from the web-based user interface and deliver the alert messages to the healthcare actor with the preferred communication channel. Furthermore, the alert agent follows the sent alert messages for the delivery acknowledgement and routes the unacknowledged alert messages to another healthcare user. The alert agent is also responsible for storing the logs of the alert messages for future inspections.
- **Simulation Agent (For test Purpose):** The simulation agent is developed mainly for test purposes. To test the full functionality of the Saphire Alert System, a component is needed to send alert message requests as if it comes from the main Saphire System. Thus, a Java-based GUI is developed where simulation alert message requests can be sent to

the Saphire Alert System. A simulation agent is running behind the simulation GUI which inserts the message information into an ACL message and sends the ACL message to the concerned alert agent. The details of the simulation agent and simulation GUI are provided in Section 4.3.

After defining the main actors in the Saphire Alert System, the general system structure is presented in Figure 4. As it can be seen from the figure, there are five major components in the Saphire Alert System. The ***Alert Data Model*** is the semantic layer and meta-data component of the system; it represents the overall semantics and knowledge of the system. All these meta-data and knowledge are covered with the development of the other components; the data models and semantic rule structures are realized with the Database – Rules & Rule Engine component. On the front side of the Saphire Alert System, the ***Web-based User Interface*** component is realized which accepts the input of the healthcare actors. The main management of the Saphire Alert System is utilized from this component. The ***Database-Rules & Rule Engine*** component is placed just behind of the web-based user interface to store the data provided by the users. All the raw data are physically stored in the Saphire Alert System Database which includes the data of the alert rules. The JESS Rule Engine [2] executes the rules for the appropriate delivery of the alert messages. The core of the Saphire Alert System is the ***Alert Manager*** component where all the alert agents are living within JADE Platform. The main responsibility of this component is to receive the alert message requests from the main Saphire System and send the alert messages to the related actors after analyzing and constructing the alert messages with the help of rules and medical data available in the Database – Rules & Rule Engine component. For the user communication of the Saphire Alert System, the ***Communication Layer*** component is working which provides the communication channels for secure e-mail, SMS and MSN Messenger instant messaging.

In the succeeding subsections, the details of each Saphire Alert System Components are provided.

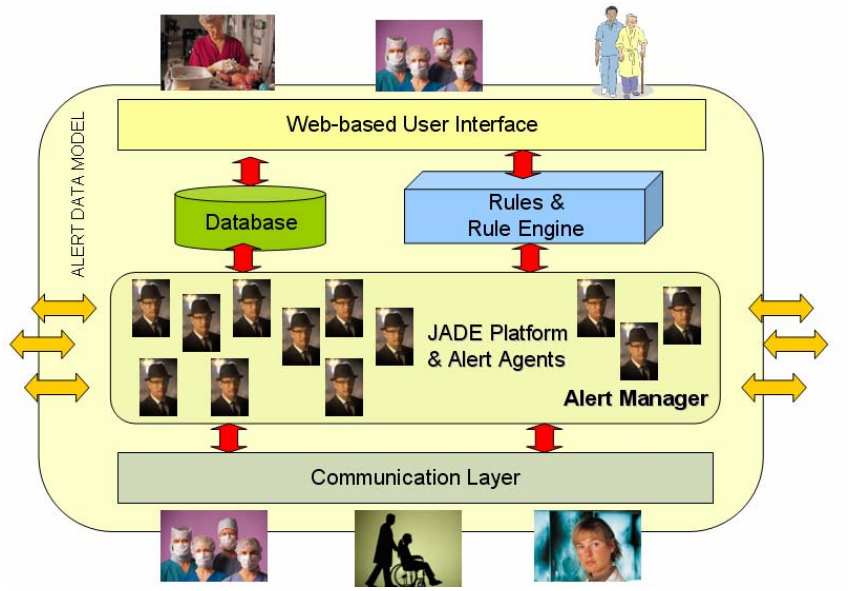


Figure 4 Saphire Alert System

4.1 Web-based User Interface

For the overall management of the Saphire Alert System, a detailed web-based user interface has been developed over the MS .NET framework 1.1. The web-based user interface has been designed and implemented to serve the healthcare actors to fulfill all their operations over the internet. Twelve different web pages have been developed for this purpose which is accessible easily with a web browser. The main purpose of the Saphire Alert System Web-based User Interface is to realize the publish-subscribe mechanism. This mechanism is based on the delivery of the right alert messages to the right healthcare actors with the specified communication channel, acknowledgement and routing facilities. The healthcare administrator has the overall authority for the publish-subscribe mechanism; as it will be mentioned with the web-based user interface designed pages, the healthcare administrator can add and invite new healthcare users to the system, manage patient-guideline pairs, assign healthcare users to

the patient-guideline pairs and also import external patient information to the Saphire Alert System with Web Service interfaces.

The other user for the web-based user interface is the healthcare actors which are medical doctors, nurses and patient relatives. The healthcare actors constitute the second main part of the publish-subscribe mechanism for alert messages. After the invitation of the healthcare user by the healthcare administrator, the healthcare user can access to the system by the provided login information and can manage the personal and contact information, define alert message receiving criteria for the main and secondary responsible patient-guideline pairs and access to the logs of alert messages. The details of each action will be given with the related web page designed for the intended aim.

The initial access page of the Saphire Alert System is the “Start Page” which can be seen in Figure 5. With this page, the healthcare actor can enter to the Saphire Alert System. With the correctly provided user name and password the healthcare actor is directed either to the “Administration Page” or “Healthcare User Page” with the role of the healthcare actor. The security between the page transfers is provided with session control mechanisms. After the login, the healthcare actor is supplied with the session tags where the role of the healthcare actor is also given. The role type of the healthcare actor disallows the user to access a page without permission, for instance a medical doctor cannot open an administration page even if the medical doctor successfully logins to the Saphire Alert System. If there is an attempt to access a page without the required sessions which are obtained with login, the user is redirected to the “Error Page” which can be seen in Figure 6.

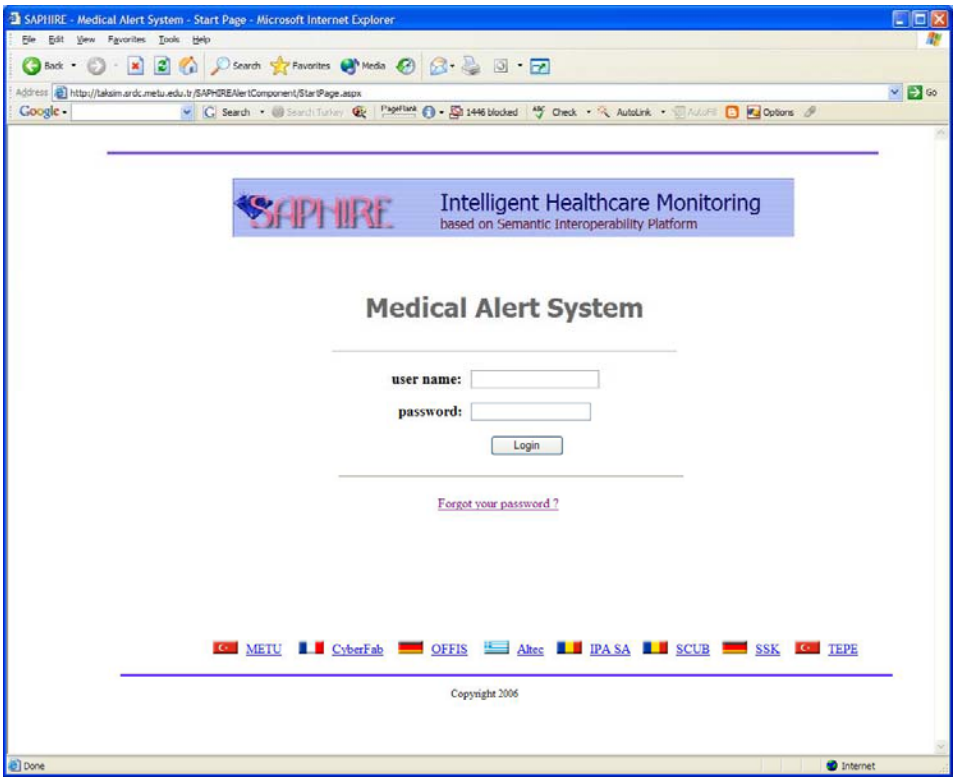


Figure 5 Saphire Alert System - Start Page

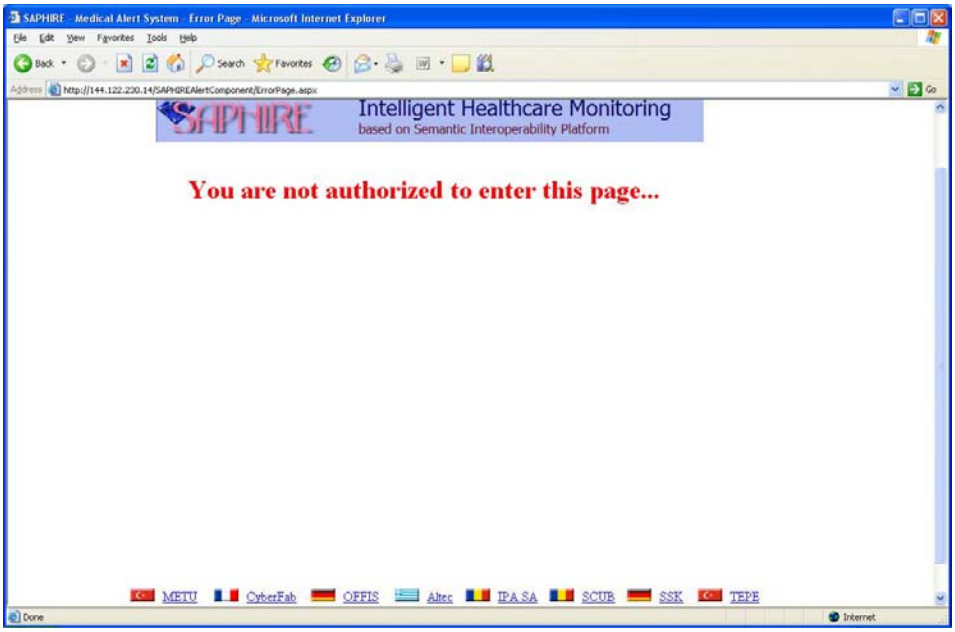


Figure 6 Saphire Alert System - Error Page

The “Start Page” has a link for users who have forgotten the password for the entrance to the system. With the page which can be seen in Figure 7, the healthcare user can obtain the password securely by e-mail. For all e-mail messaging, the encrypted e-mails are structured with the public key of the recipient and can only be decrypted by the private key of the user. DER encoded binary X.509 (.CER) format is used for encryption and decryption. It is assumed that the Saphire Alert System is fed with the related public key of the user’s e-mail. Without the installed private key, the healthcare user cannot read the content of the received e-mail. This option is vital for the healthcare domain where the patient data should be stored and transferred within secure and private environment. A secure e-mail can be seen in the Figure 8 where the required private key has not been installed to the system to access the content of the e-mail. Whereas in Figure 9, the user has the private key which is installed to the system and the content can be decrypted by pressing the “Continue” button.

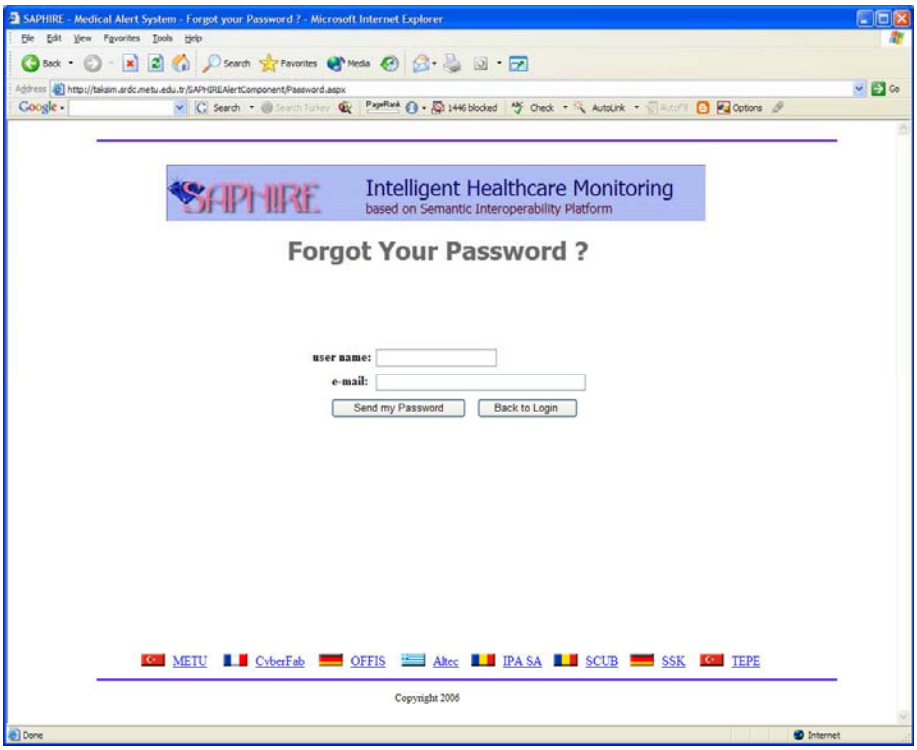


Figure 7 Saphire Alert System - Forgot Password Page

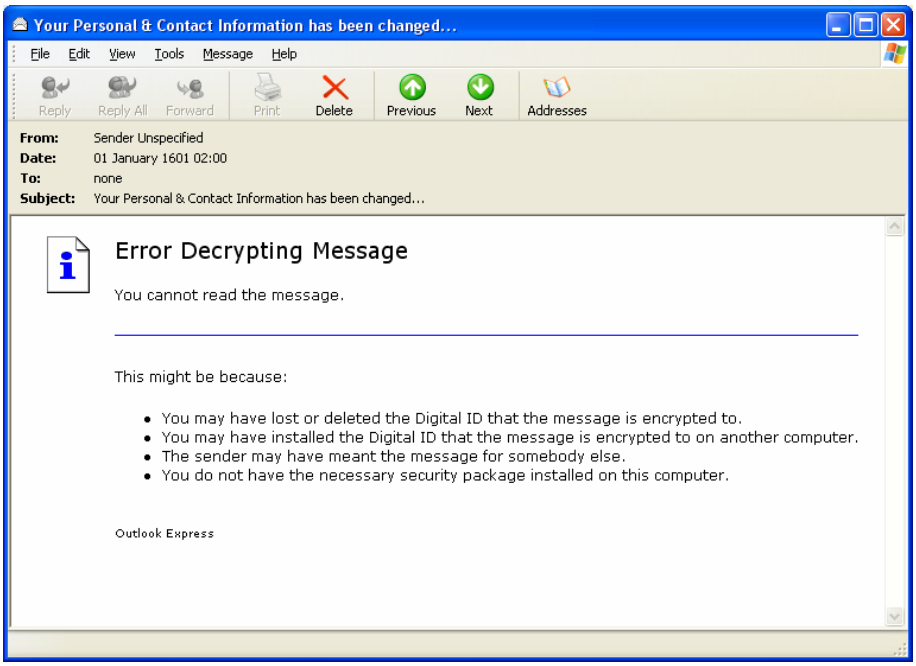


Figure 8 Secure e-mail - Error Decrypting Message

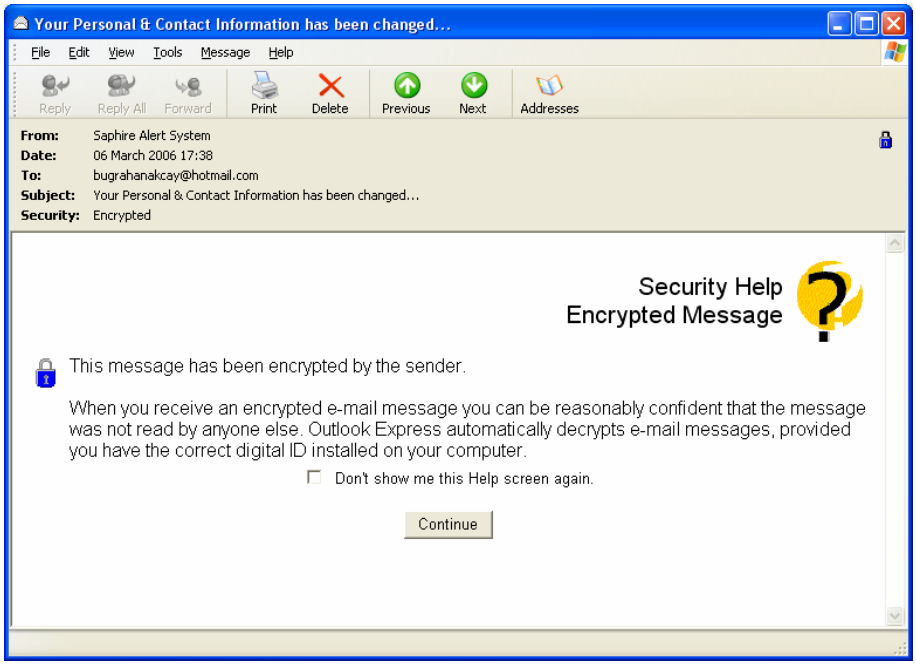


Figure 9 Secure e-mail - Have Right to Access

After the successful login to the Saphire Alert System, the user is directed to the "Healthcare Administration Page" if the user has a healthcare administrator role.

Under the healthcare administration page which can be seen in Figure 10, the healthcare administrator has four options which can be accessible by "Go" buttons. The sub-pages of healthcare administration page are as follows;

- Manage Patient ⇔ Guidelines Page
- Manage Guidelines ⇔ Nurse(s) & Doctor(s) & Patient Relative(s) Page
- Add New Healthcare User Page
- Import Patient Data From External System

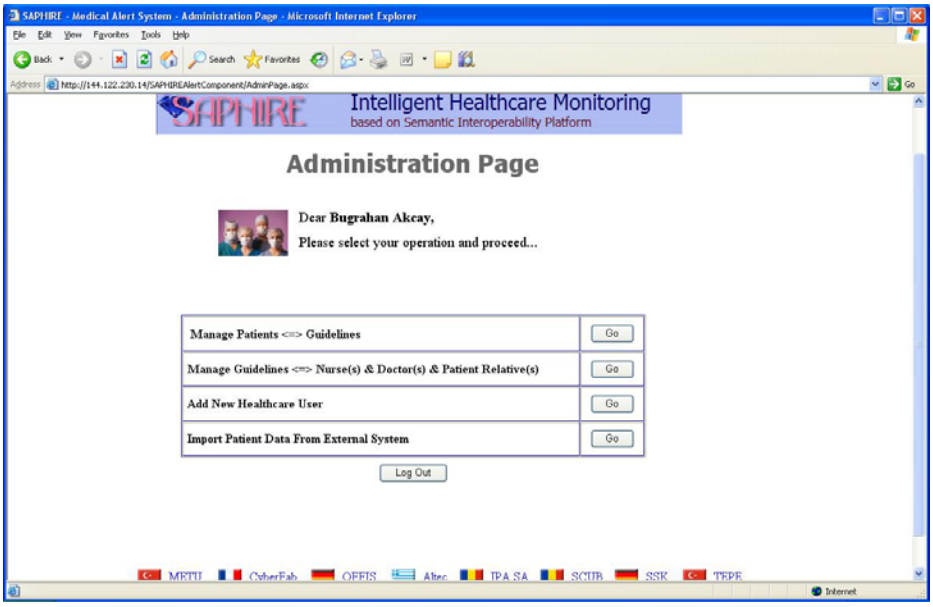


Figure 10 Saphire Alert System - Administration Page

The first functionality served to the healthcare administrator is managing the patient-guideline pairs. As it can be seen in Figure 11 with the "Manage Patient-Guideline Page", the healthcare administrator can assign a patient to a related guideline. While assigning a patient, the system shows the patient information after each selection. Additionally, the structured patient-guideline is available in the list. The last functionality of this page is deleting the patient-guideline pairs by selecting the patients and guidelines from the drop down lists. As in all Saphire Alert System Web-based User Interface pages, the users are informed with the changes in the system. These informative actions to the user are in both

ways; one is on screen messages the other is with informative e-mails. Some informative e-mail formats will be given in the proceeding parts of the study.

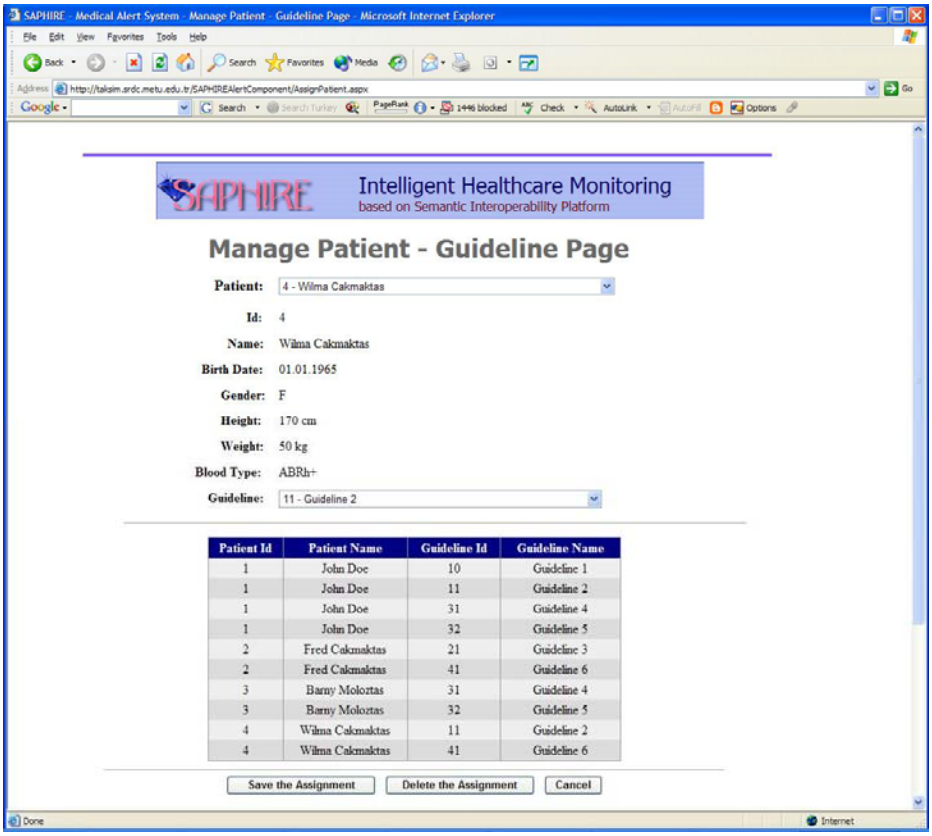


Figure 11 Saphire Alert System – Manage Patient-Guideline Page

The second functionality which is presented to the healthcare administrator is assigning healthcare actors to the coupled patients and guidelines. With the page seen in Figure 12, the healthcare administrator can give responsibility to doctors, nurses and patient relatives for the selected patient-guideline pairs. For each healthcare actor group, the healthcare administrator can assign more than one actor as responsible. After the assignment, the assigned healthcare actors are informed with auto-generated secure e-mails to define their alert message receiving rules for the related patient-guideline. In Figure 13, the overview of the guideline assignment information e-mail can be seen.

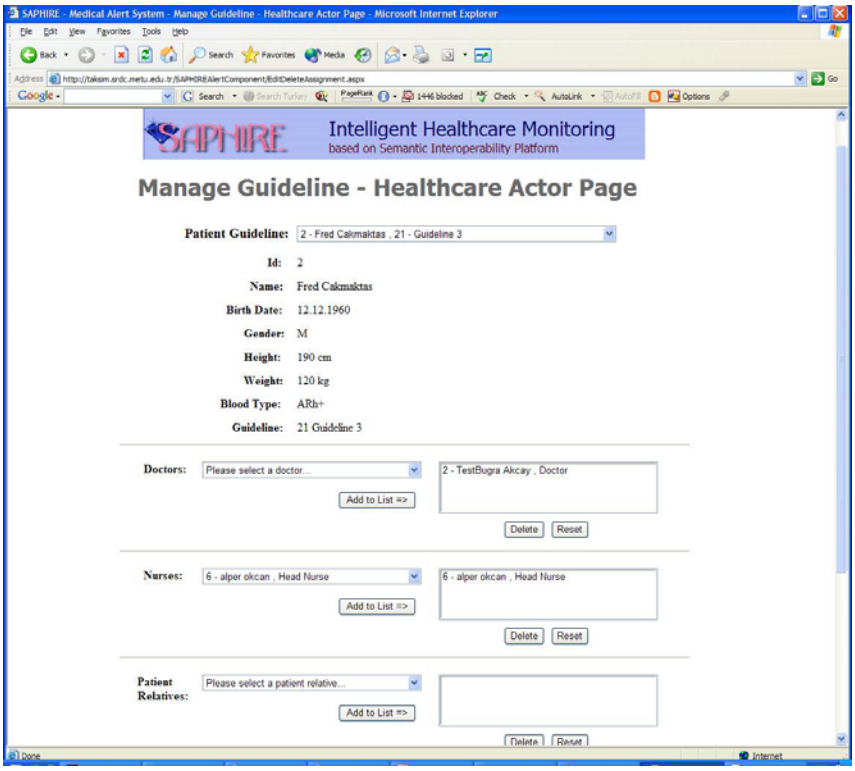


Figure 12 Saphire Alert System – Manage Guideline - Healthcare Actor Page

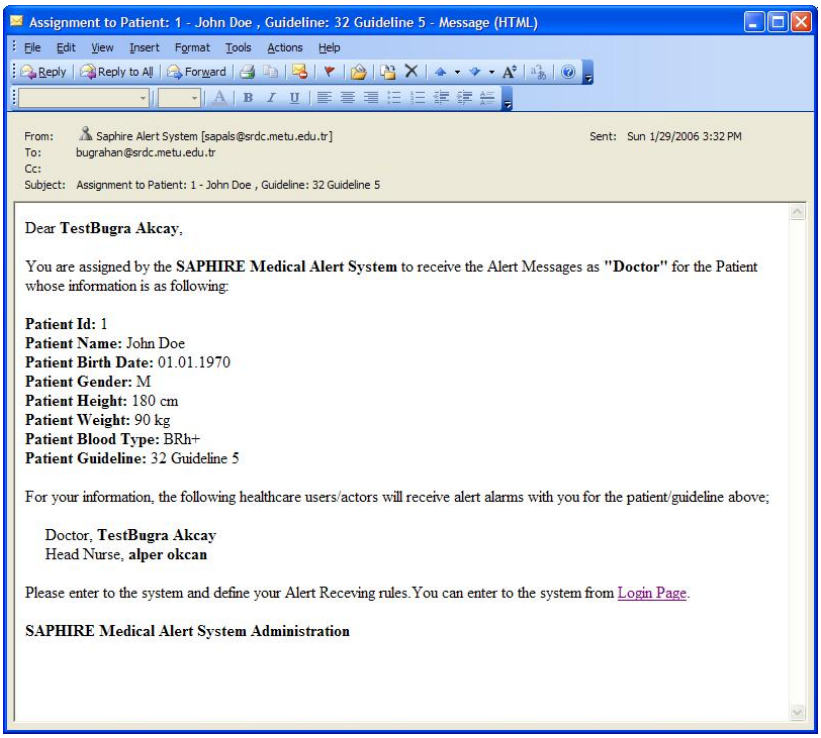


Figure 13 Saphire Alert System – Guideline Assignment Information e-Mail

Another action which is accessible from the "Healthcare Administration Page" is, adding a new user to the Saphire Alert System. The healthcare administrator can add and invite a new healthcare actor by filling the primitive information which is user name, first name, surname and primary e-mail as can be seen in Figure 14. One of the most important fields is the role of the new user; the healthcare administrator can select the role of the user from the drop down list. After the addition of the new user to the Saphire Alert System, the new user is informed with an invitation e-mail where the user name and auto-generated password are included. The welcome e-mail can be seen in Figure 15.

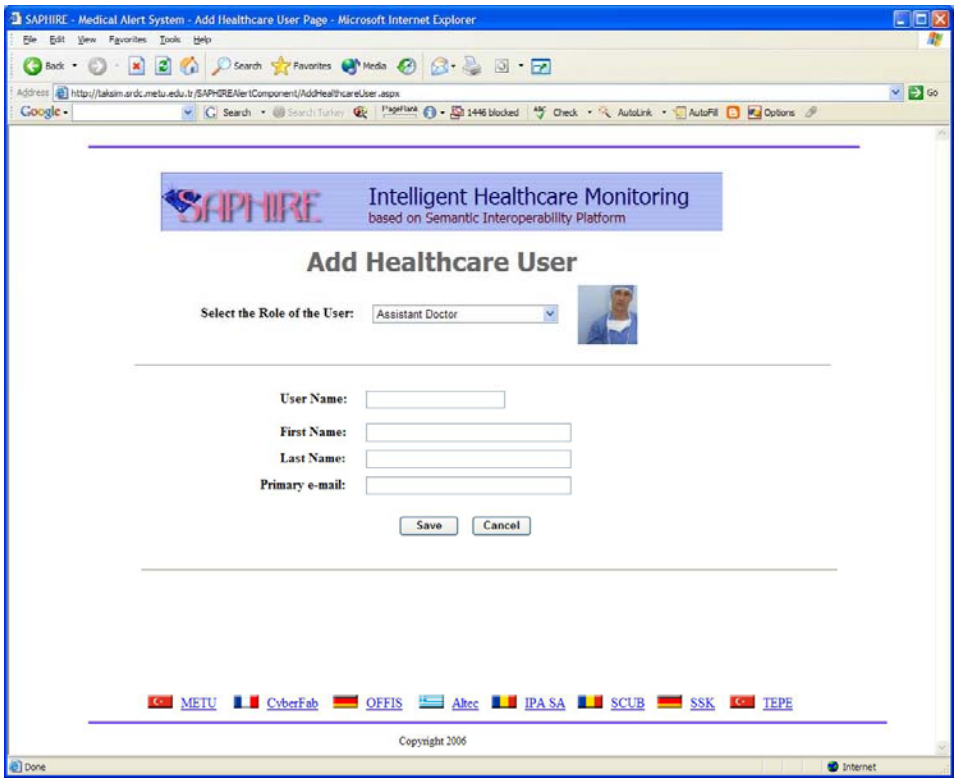


Figure 14 Saphire Alert System - Add Healthcare User Page

The final available action that the healthcare administrator can fulfill is importing external patient data from other healthcare systems. For this task, the page which can be seen in Figure 16 is designed. The import operation is based on the Web Service technology where only the WSDL file is enough for accessing the Web Service and invoking it. After providing the Web Service

WSDL address which will return all the patient data in XML format, the "Get Service Info" button will parse the WSDL file and list all the available types and methods which the Web Service can offer. As the patient data are highly secured and private, the Web Service can only be invoked with right user name and password. If the Web Service invocation is successful, a list is created with the patients' data that are returned by the Web Service. The obtained patient data are inserted to the Saphire Alert System Database. The insertion of the received patient data is in two cases; if the id of the patient cannot be found in the Saphire Alert System Database, it is inserted as a new row. Whereas, if the patient has been inserted before, the data of the patient is updated with the currently obtained patient information. The Web Service result which is in XML format can be seen in Figure 17.

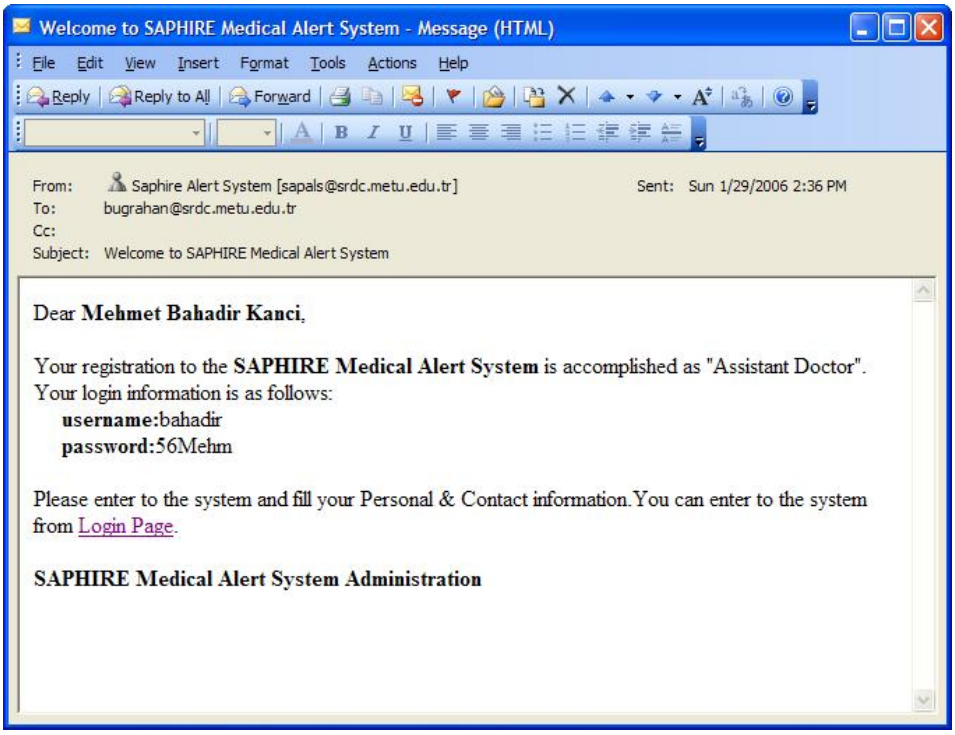


Figure 15 Saphire Alert System - Welcome to SAPHIRE Medical Alert System

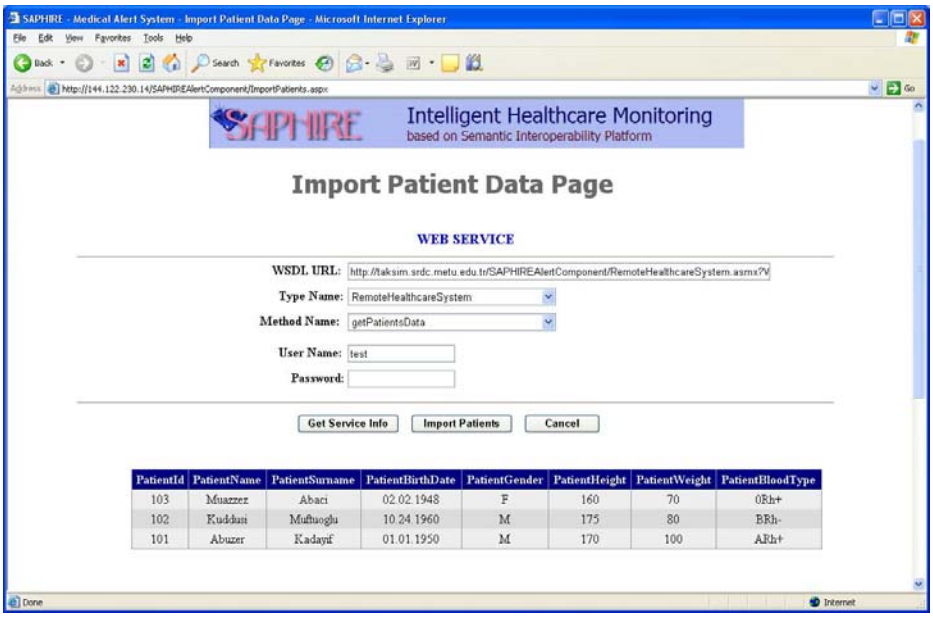


Figure 16 Saphire Alert System - Import Patient Data Page

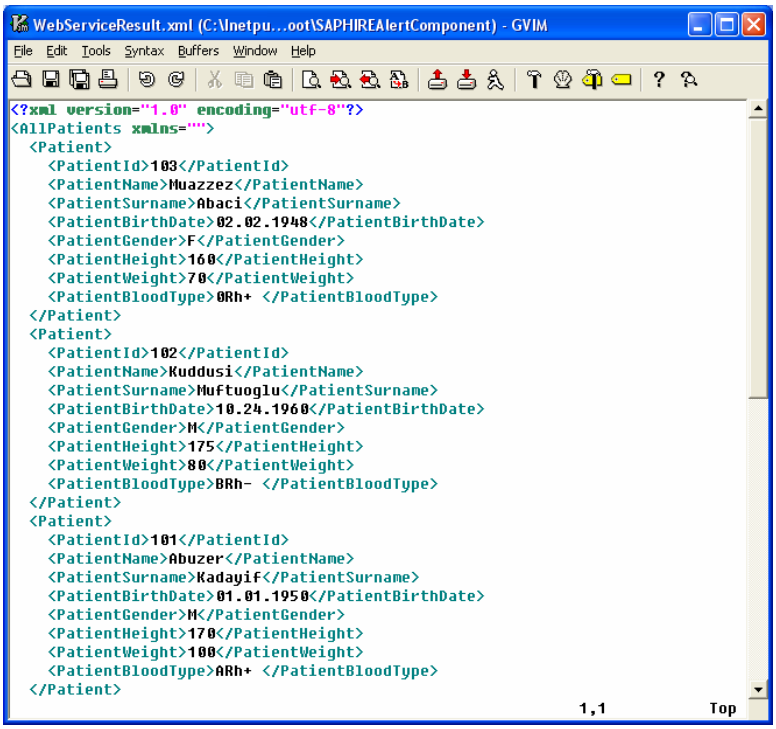


Figure 17 Import Patient Web Service Result

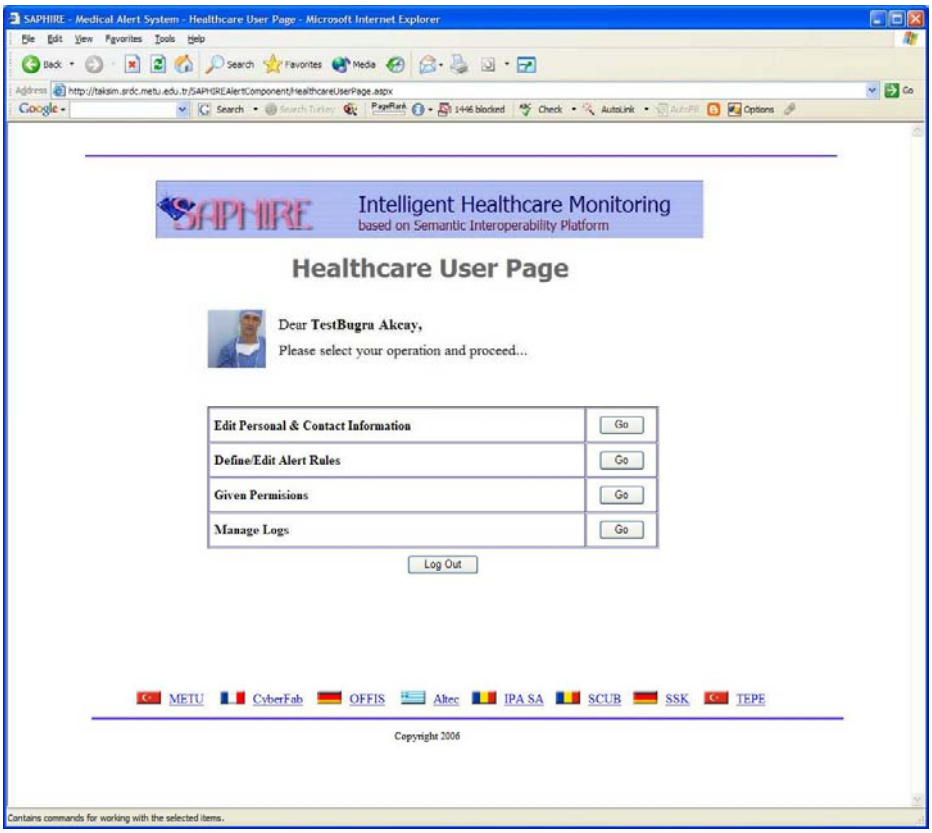


Figure 18 Saphire Alert System - Healthcare User Page

The other healthcare actor who can access and use the functionalities of Saphire Alert System Web-based User Interface is composed of medical doctors, nurses and patient relatives. As described before, healthcare users are added to the system by healthcare administrator. The Saphire Alert System offers four main functionalities for the healthcare users which are (Figure 18);

- Edit Personal & Contact Information Page
- Define/Edit Alert Rules Page
- Given Permissions Page
- Manage Logs Page

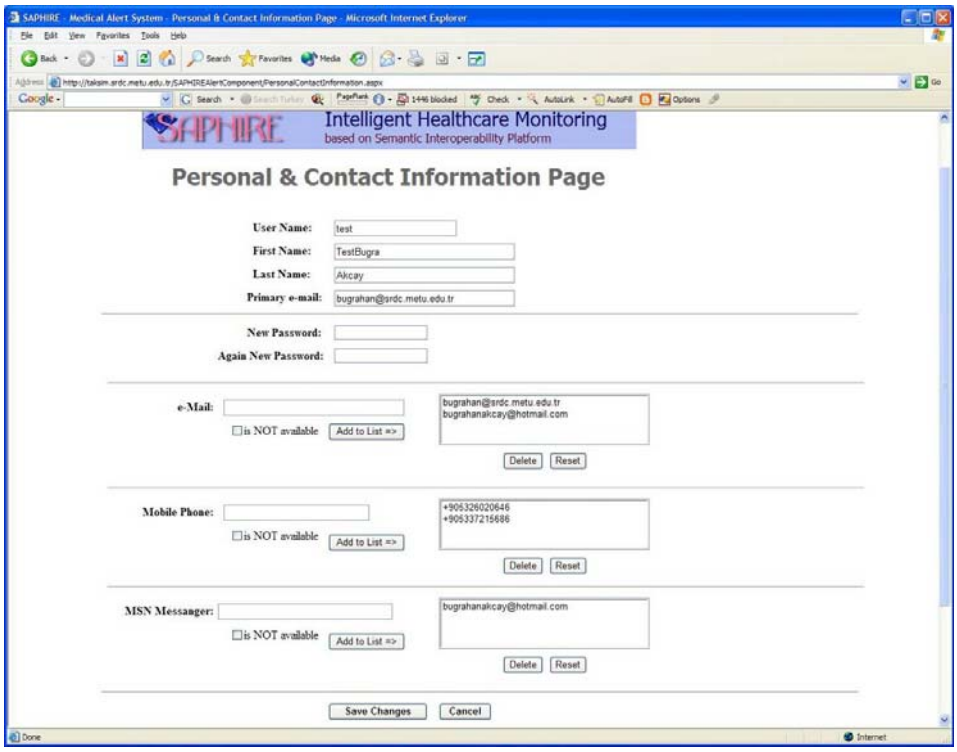


Figure 19 Saphire Alert System - Personal & Contact Information Page

The first task which can be done by healthcare user from the web-based user interface is to define the personal information and contact information where the alert messages will arrive. As it can be seen from Figure 19, the healthcare user can change the user name, first name, last name, primary e-mail, where all the informative e-mails arrive and password. Additionally, for the alert messages e-mail, mobile phone and MSN Messenger contact points can be defined more than once for each. All the changes are saved to the system with “Save Changes” button and the healthcare user is informed by an e-mail to his/her primary e-mail address with the following format in Figure 20.

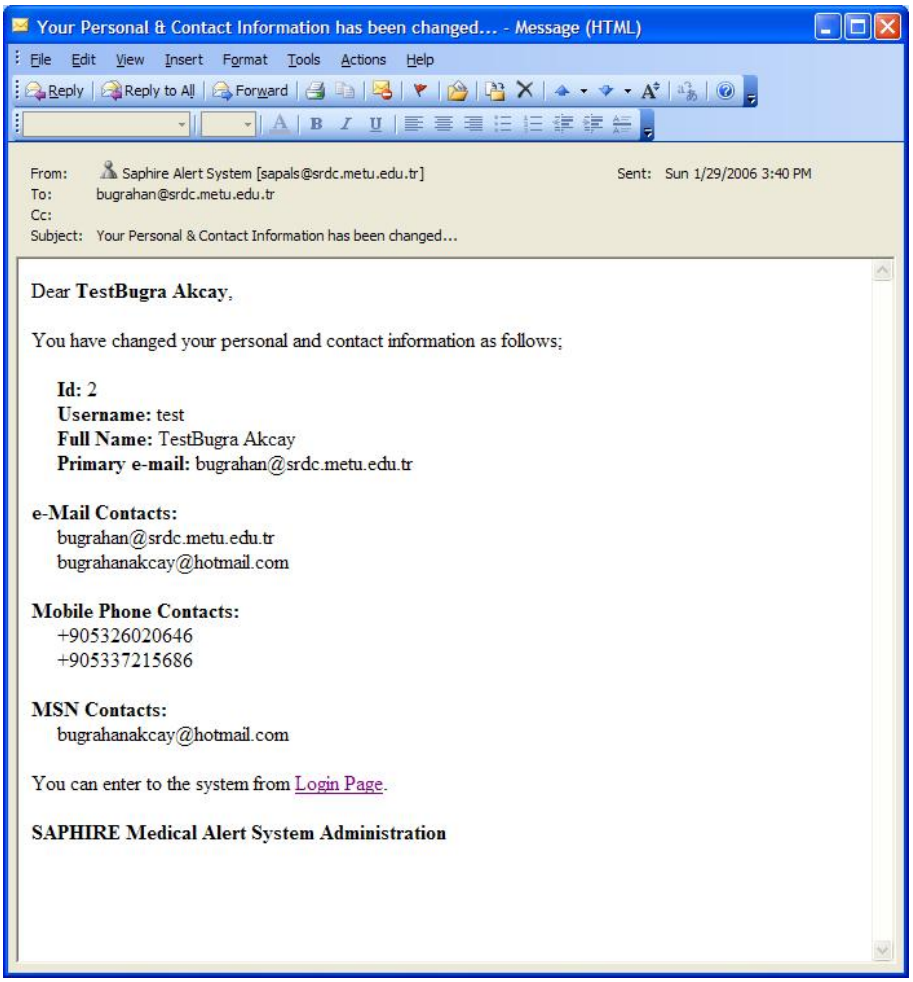


Figure 20 Saphire Alert System - Personal & Contact Information e-Mail

One of the most important functionality that is served to the healthcare user is the ability to define alert message receiving rules. As the details of the rules are elaborated in the following subsection, there are mainly three categories which can be seen in Figure 21. The healthcare user is presented with the assigned patient guideline list that the rules are defined for the selected patient-guideline couple. Five alert message urgency levels have been defined;

- Urgent
- Critical
- Important
- Reminder
- Request

The alert message receiving rules are based on the urgency levels because the urgency level mainly determines response time and other issues that are related with rules. The first type of rule that can be defined by the healthcare user is changing the urgency level of an alert message for some diseases. For instance, our patient has some problems which are very important for cardiovascular disease, so we can change the urgency level of an alert message with disease type Cardiovascular from “Important” to “Critical” or from “Critical” to “Urgent”. This rule type is optional but the second rule format which determines the communication channel, acknowledgement request, number of attempts, time intervals for each attempt and whether the sending of alert message is mandatory. For instance, if the urgency level of an alert message is “Critical”, the user can declare that the “Critical” alert messages should be delivered by SMS from a specific mobile phone number. Additionally, the user can check the acknowledgement box if the acknowledgement is important for these type of alert messages. The alert message will be sent n times with m seconds interval till the acknowledgement with the preferences of the user. The acknowledgement protocol changes for each communication channel. For e-mail, a single e-mail reply is being waited for the system; for SMS, the delivery of the SMS is being checked from the GSM operator; for MSN Messaging, the response of the user is waited by the system from the MSN Messaging window. If the acknowledgement cannot be received within the specified period, the alert message is resent again as much as specified by the user. The other preference that can be defined by the user is the “Must Send” option, if the acknowledgement cannot be received within the predefined specifications, the alert message can be routed to another healthcare user if the “Must Send” box is checked.

The third part of the “Define/Edit Alert Rules Page” which can be seen in Figure 21 is about giving permissions to other healthcare users for the routing of the alert messages. As defined in the previous paragraph, if the acknowledgement is not received and must send option is active, the undelivered alert message is routed to other permitted users. All these changes are saved to the system by

"Save Changes" button and an informative e-mail is sent to the user within the format in Figure 22. If some healthcare users are given permission for the routed alert messages, those users are also informed with e-mails and are expected to define how they want the alert messages to be delivered through the system.

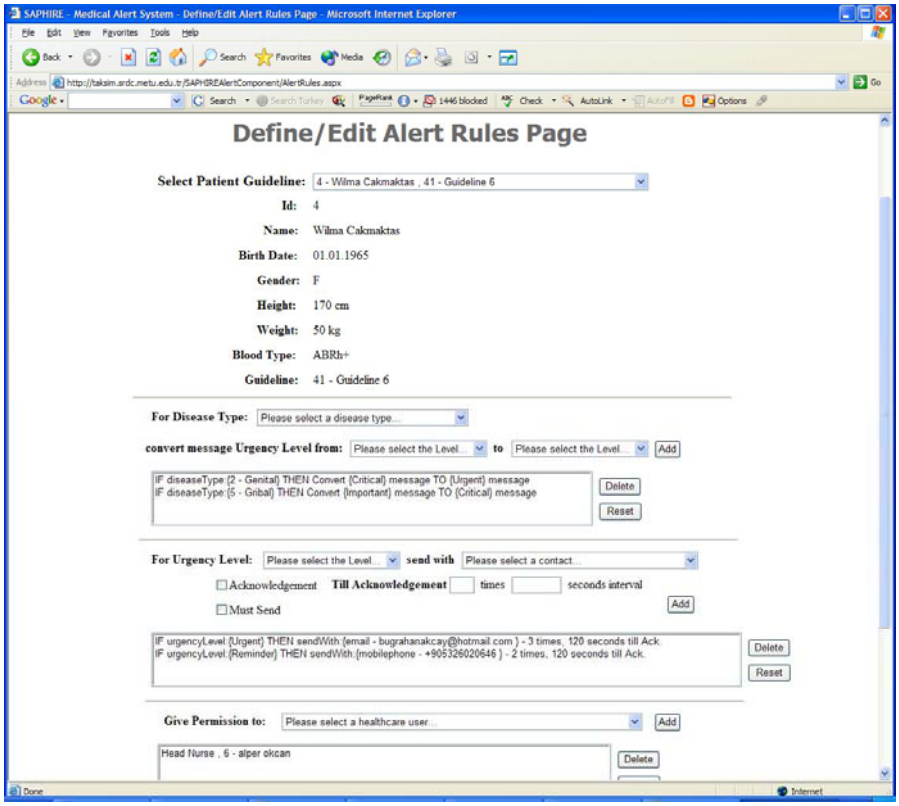


Figure 21 Saphire Alert System - Define/Edit Alert Rules Page

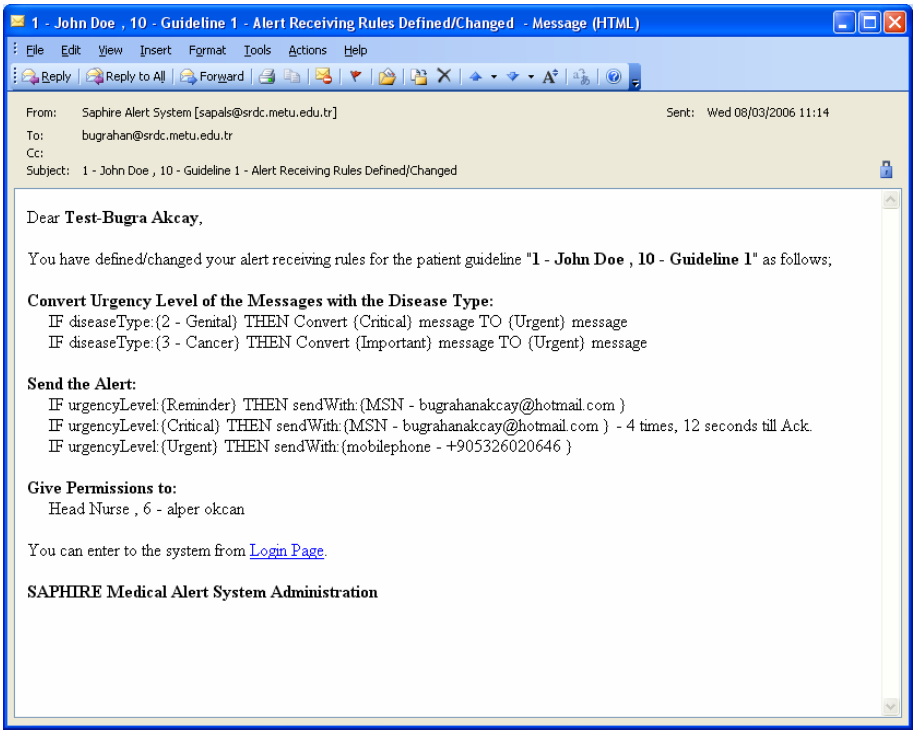


Figure 22 Saphire Alert System - Alert Receiving Rules Defined/Changed e-mail

The healthcare user has right to access the "Given Permission Page" which can be seen in Figure 23. This page is designed for defining the alert message receiving rules for the routed alert message. If any other healthcare user assigns and gives permissions to another healthcare user for the routed alert messages, the alert message receiving rules can be defined from this page. The semantic of the page is same with the previous page, "Define/Edit Alert Rules Page". The user is prompted with a patient-guideline list and the rules for communication channels, disease type, and acknowledgement specifications can be easily defined. As in all pages, the healthcare user is informed with an e-mail after saving the changes to the Saphire Alert System.

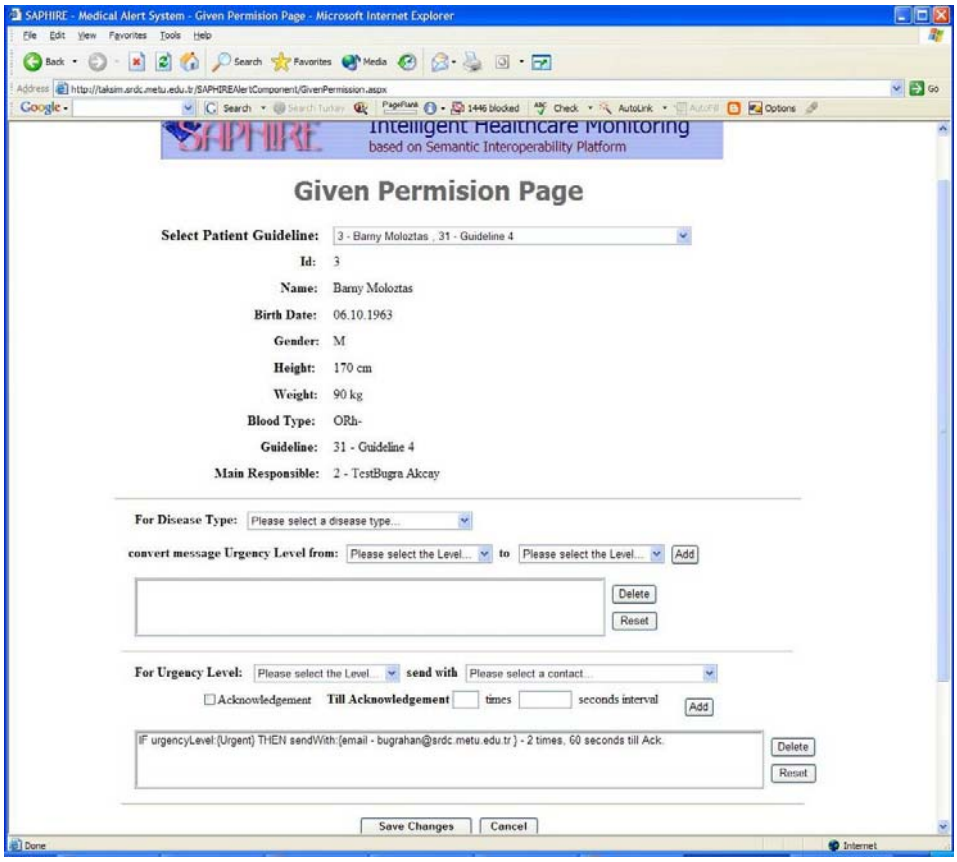
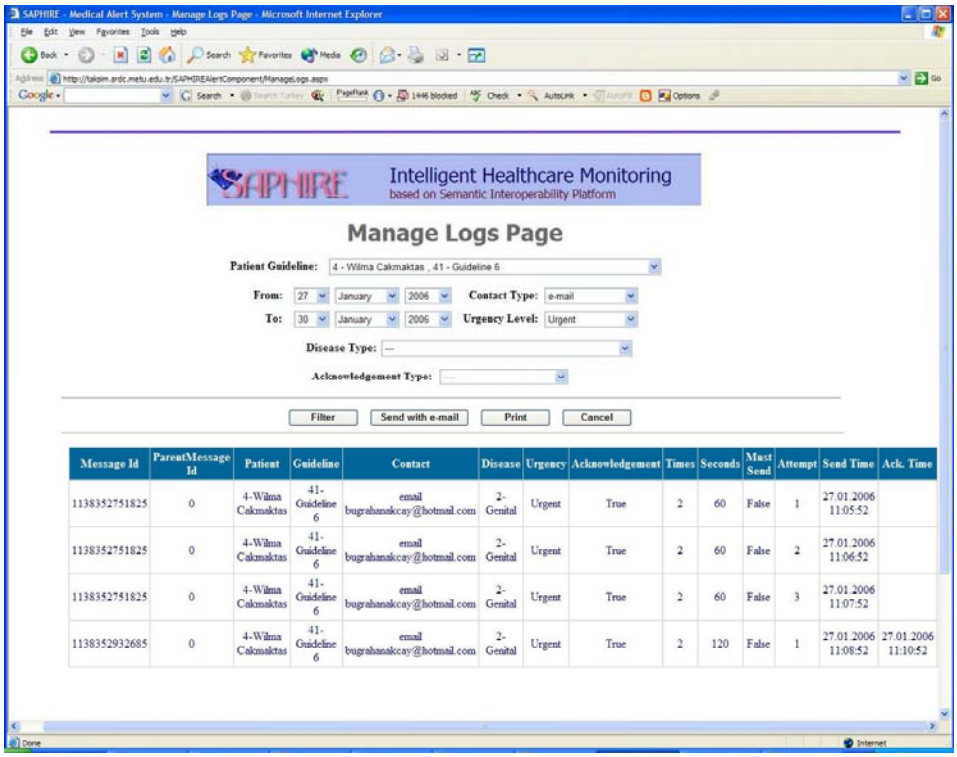


Figure 23 Saphire Alert System - Given Permission Page

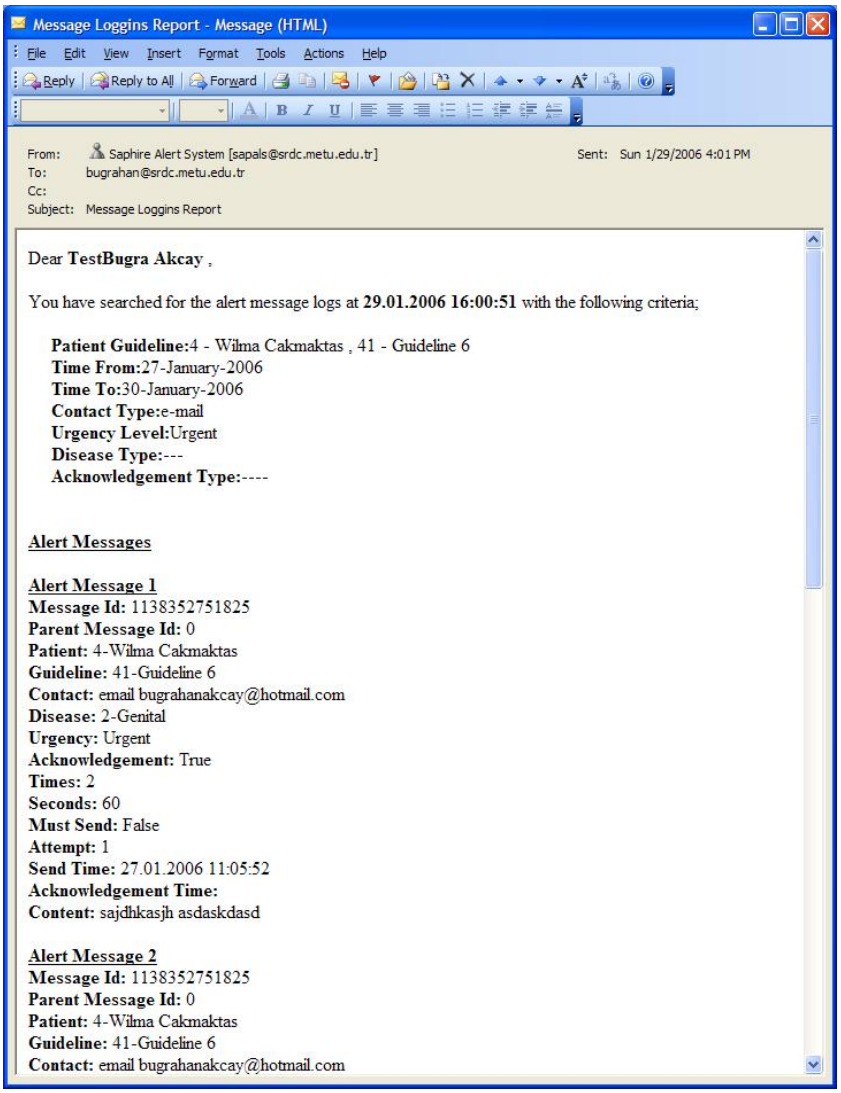
The final page which is accessible from the healthcare user main page is the "Manage Logs Page". This page is designed to access the alert message logs for the owned patient-guideline pairs. As it can be seen from the Figure 24, a filtering mechanism has been designed for the alert message logs; the messages can be filtered by the time, contact type (e-mail, SMS, MSN Messenger), urgency level, disease type and acknowledgement type. With the "Filter" button, the alert messages complying with the provided criteria are listed on the page. Furthermore, the healthcare user can request to receive the logs of alert messages by e-mail which can be seen in Figure 25. The healthcare user can also directly print the alert message logs by "Print" button on the page.



Message Id	ParentMessage Id	Patient	Guideline	Contact	Disease	Urgency	Acknowledgement	Times	Seconds	Must Send	Attempt	Send Time	Ack. Time
1138352751825	0	4-Wilma Cakmaktas	41-Guideline 6	email bugrahanakcay@hotmail.com	2-Genital	Urgent	True	2	60	False	1	27.01.2006 11:05:52	
1138352751825	0	4-Wilma Cakmaktas	41-Guideline 6	email bugrahanakcay@hotmail.com	2-Genital	Urgent	True	2	60	False	2	27.01.2006 11:06:52	
1138352751825	0	4-Wilma Cakmaktas	41-Guideline 6	email bugrahanakcay@hotmail.com	2-Genital	Urgent	True	2	60	False	3	27.01.2006 11:07:52	
1138352932685	0	4-Wilma Cakmaktas	41-Guideline 6	email bugrahanakcay@hotmail.com	2-Genital	Urgent	True	2	120	False	1	27.01.2006 11:08:52	27.01.2006 11:10:52

Figure 24 Saphire Alert System - Manage Logs Page

All the described pages are fully functioning and can be accessible from the Internet. In the next section, the details of the Saphire Alert System Database and technical details of rules will be provided.



Message Loggins Report - Message (HTML)

File Edit View Insert Format Tools Actions Help

Reply | Reply to All | Forward

From: Saphire Alert System [sapals@srdc.metu.edu.tr] Sent: Sun 1/29/2006 4:01 PM
To: bugrahan@srdc.metu.edu.tr
Cc:
Subject: Message Loggins Report

Dear **TestBugra Akcay** ,

You have searched for the alert message logs at **29.01.2006 16:00:51** with the following criteria;

Patient Guideline:4 - Wilma Cakmaktas , 41 - Guideline 6
Time From:27-January-2006
Time To:30-January-2006
Contact Type:e-mail
Urgency Level: Urgent
Disease Type:---
Acknowledgement Type:----

Alert Messages

Alert Message 1
Message Id: 1138352751825
Parent Message Id: 0
Patient: 4-Wilma Cakmaktas
Guideline: 41-Guideline 6
Contact: email bugrahanakcay@hotmail.com
Disease: 2-Genital
Urgency: Urgent
Acknowledgement: True
Times: 2
Seconds: 60
Must Send: False
Attempt: 1
Send Time: 27.01.2006 11:05:52
Acknowledgement Time:
Content: sajdhkasjh asdaskdasd

Alert Message 2
Message Id: 1138352751825
Parent Message Id: 0
Patient: 4-Wilma Cakmaktas
Guideline: 41-Guideline 6
Contact: email bugrahanakcay@hotmail.com

Figure 25 Saphire Alert System - Message Logging Report e-Mail

4.2 Database – Rules & Rule Engine

The data about patients, guidelines, healthcare users, alert messages and all the related entities about Saphire Alert System are stored in this component. Furthermore, the alert messages are sent to the healthcare users after some analysis about the delivery specifications. This analysis is based on the rule-executions by JESS Engine, also the raw data that are used in the rule facts and rule formats are taken from the Saphire Alert System Database. In the succeeding two subsections, the details of the Saphire Alert System Database and Rule Mechanisms will be elaborated.

4.2.1 Saphire Alert System Database

Saphire Alert System uses PostgreSQL 8.0 database to store the necessary data that are to be used in sending the alert messages to related parties (medical doctors, nurses, patient relatives). The tables in the database are described in the following sections.

This database has thirteen tables which are all related with sending the alert messages. The general view of the Saphire Alert System Database can be seen in Figure 26.

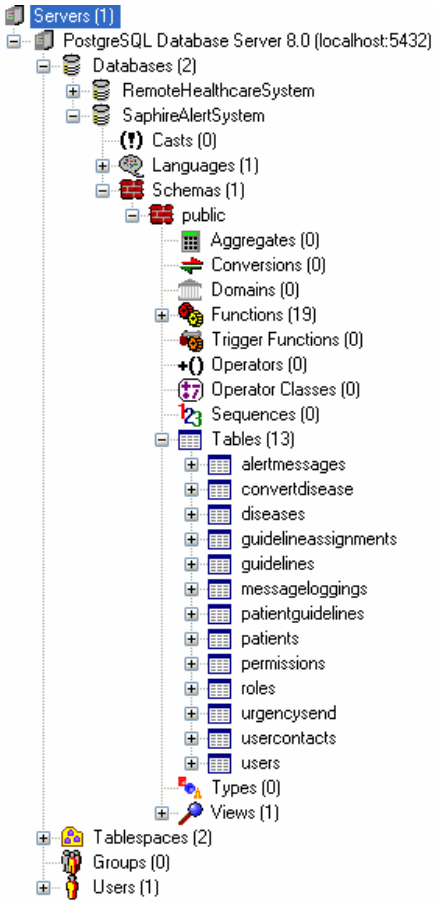


Figure 26 Saphire Alert System Database

Alert Messages table

This table is utilized for storing alert messages that are going to be sent. Messages that have been sent are logged to the "Message Loggings" table, and the original messages are stored in this table.

Detailed information about the message is also stored in this table as column values. This information includes "Guideline ID" of the guideline that triggered the alert, "Patient ID" of the patient the alert is related to, the related "Disease ID", "Urgency" and other related attributes. The "Parent Message ID" is stored if the message is routed from any other alert message. More information about the table can be found below in Table 1 where the primary keys are underlined.

Table 1 Alert Messages table

Name	Domain
Message ID	String
Parent Message ID	String
Patient ID	Integer
Guideline ID	Integer
Contact ID	Integer
User ID	Integer
Disease ID	Integer
Urgency	String
Must Send	Boolean
Acknowledgement	Boolean
Times	Integer
Seconds	Integer
Message Content	String

Convert Disease table

This table stores information for the rule execution for converting diseases. When a healthcare user adds a new rule for converting the urgency level of a specific disease, the raw data for the rule is stored in this table. "From" and "To"

attributes represents the urgency levels. The last attribute, “Parent User ID”, is set to understand whether this rule is owned as a primary responsible of the patient-guideline couple or as a secondary responsible. As Saphire Alert System enables routing for unacknowledged alert messages, the alert messages receiving rule mechanism is applicable for both main receivers and secondary receivers.

Table 2 Convert Disease table

Name	Domain
Convert ID	Integer
User ID	Integer
Patient ID	Integer
Guideline ID	Integer
Disease ID	Integer
From	String
To	String
Parent User ID	Integer

Diseases table

This table is designed to store disease information. Mapping “Disease ID” to “Disease Name” and related description is performed within this table.

Table 3 Diseases table

Name	Domain
Disease ID	Integer
Disease Name	String
Disease Comment	String

Guideline Assignments table

This table stores the assignments between healthcare users and patients-guidelines pairs. The healthcare administrator assigns the healthcare users who will be responsible for the alert messages owned by patient-guideline couple.

Table 4 Guideline Assignments table

Name	Domain
User ID	Integer
Patient ID	Integer
Guideline ID	Integer

Guidelines table

Information about the guidelines is stored in this table. "Guideline Name", "Guideline ID" and description are kept in this table.

Table 5 Guidelines table

Name	Domain
Guideline ID	Integer
Guideline Name	String
Guideline Description	String

Message Loggings table

This table is directly related with the "Alert Message" table. This table stores the information about the alert message sending attempts with time and acknowledgement information.

Table 6 Message Loggings table

Name	Domain
Message ID	String
Attempt	Integer
Send Time	Timestamp
Acknowledgement Time	Timestamp

Patient Guidelines table

This table stores the guideline-patient pairs that have been coupled by the healthcare administrator.

Table 7 Patient Guidelines table

Name	Domain
Patient ID	Integer
Guideline ID	Integer

Patients table

Demographic information of patients is recorded to the "Patients" table. The table has eight columns for keeping several types of information about the patients.

Table 8 Patients table

Name	Domain
Patient ID	Integer
Patient Name	String
Patient Surname	String
Patient Birth date	Date
Patient Gender	Char
Patient Height	Integer
Patient Weight	Integer
Patient Blood Type	String

Permissions table

This table is designed for the routing operations. The healthcare user can give permissions to other healthcare users in case the alert message cannot be received by him/her. The unacknowledged alert messages are routed to these permitted healthcare users. "User ID" is the primary responsible for the "Guideline ID" of "Patient ID". The "Given User ID" is the secondary responsible for the patient-guideline couple.

Table 9 Permissions table

Name	Domain
User ID	Integer
Patient ID	Integer
Guideline ID	Integer
Given User ID	Integer

Roles table

In Saphire Alert System, it is possible to assign different roles (such as doctor, nurse, patient relative etc) to healthcare members. These roles will enable customization of services offered by the Saphire System and customization of the Saphire Alert System Web-based User Interfaces.

Table 10 Roles table

Name	Domain
Role ID	Integer
Parent Role ID	Integer
Role Name	String
Role Description	String

Urgency Send table

This table is designed to store the needed data for the execution of the main Saphire Alert System Rule. As described before and also will be detailed in the next subsection, the healthcare user can define the alert message receiving specifications by this rule; the contact type (e-mail, SMS, MSN Instant Messaging), contact number, acknowledgement request, attempt number, time interval and must send options. All these are specified for a patient-guideline couple and for an urgency level. “Parent User ID” attribute is added to the table for the routing purpose to determine if the owner of this rule is the main responsible of the patient-guideline couple or the secondary responsible with routing.

Table 11 Urgency Send table

Name	Domain
Send ID	Integer
User ID	Integer
Patient ID	Integer
Guideline ID	Integer
Urgency Level	String
Contact ID	Integer
Acknowledgement	Boolean
Times	Integer
Seconds	Integer
Must Send	Boolean
Parent User ID	Integer

User Contacts table

This table stores information about the contact details of healthcare user. This information will be used when sending an alert message, thus it is vital to have working contact information in this table.

Table 12 User Contacts table

Name	Domain
Contact ID	Integer
User ID	Integer
Contact Type	String
Contact Number	String
Contact is available	Boolean

Users table

This table is where healthcare user data is stored in the database. User's data as well as their roles which determine their permissions are stored in this table.

Table 13 Users table

Name	Domain
User ID	Integer
Username	String
User First Name	String
User Surname	String
User Role	Integer
User Password	String
User Email	String

4.2.2 Saphire Alert System Rules & Rule Engine

The Saphire Alert System needs a rule-based mechanism to process the received alert message further. The alert message requests arrive to the Saphire Alert System with the following tuples;

- **Patient:** This is the patient identification number which the alert message is intended for.
- **Guideline:** This is the guideline identification number which the alert message is generated for.
- **Disease:** This is the disease identification number which the alert message is related with.
- **Alert Message:** This attribute is a list with three sub attributes; "Urgency Level", "Role Type" and "Message Content". The alert message requests arrive with a generic role type, after that the responsible healthcare users are found from the system with that role identification number. The rules are executed for those specific healthcare users in the Saphire Alert System.

Before the implementation phase, some rule systems have been analyzed which can be utilized in the Saphire Alert System. RuleML [3] is one of them which has the following popular engines and APIs; JSR-000094 Java Rule Engine API [4], Mandarax RuleML [5], OO jDREW [6]. Additionally, Semantic Web Rule Language (SWRL) [7] is one of the other candidates which are based on OWL

DL [8] and OWL Lite [9] with unary/binary Datalog RuleML sublanguages but this standard lacks of a mature engine for execution. After all these analysis, JESS is selected for rule operations. JESS has a mature engine and works well with JADE Agents. Below general rule formats can be found which are needed for the Saphire Alert System;

1. IF diseaseType = {?x} THEN convert messageUrgencyLevel
   {Urgent, Critical, Important, Reminder, Request}
   to {Urgent, Critical, Important, Reminder, Request}

2. IF messageUrgencyLevel = {Urgent, Critical, Important, Reminder, Request} THEN
   sendMessageWith = {e-mail, SMS, Instant Messaging}

3. IF messageUrgencyLevel = {Urgent, Critical, Important, Reminder, Request} THEN
   waitFor = {Acknowledgement, Not}

4. IF messageUrgencyLevel = {Urgent, Critical, Important, Reminder, Request} THEN
   sendMessage {n} times with {n} seconds interval
   till the Acknowledgement

5. IF messageUrgencyLevel = {Urgent, Critical, Important, Reminder, Request} THEN
   Message = {MustSend, Not}

All these meta-rules are specific for <patient, guideline, healthcare user> triples. As described in the web-based user interface part, these rules are constructed by the healthcare users for the assigned patient-guideline pairs. The first meta-rule is utilized for changing the urgency level of an alert message for some diseases. If the healthcare user seems a need for the alert messages with some disease types should be processed more urgent specifications, he/she can state that for

this type of disease change the urgency level from “Critical” to “Urgent” or “Request” to “Important”. This meta-rule is firstly executed with the arrival of the alert message requests because for the rest of the rules, the urgency level is single criteria for the results. The alert agent creates the rules within the JESS format by using “defrule”, the needed components of the rule are taken from the Saphire Alert System Database. The urgency level and disease type of the received alert message request are saved to the JESS engine as facts by the alert agent. After the run of the JESS engine, the alert agent can obtain the new urgency level. This mechanism is similar for the other rule executions.

The meta-rules from 2-5 are represented as one rule which is also presented in the previous subsection. With the obtained urgency level after the execution of the rules which changes the urgency level, the communication channel, acknowledgment request and time specification, and must send option are determined by the rules. By the execution of the rule the communication channel can be obtained, the contact type; e-mail, SMS, MSN Instant Messaging and specific contact number for them. Furthermore, with the request of the healthcare user, the rule engine can determine for this urgency level, whether it is needed acknowledgement from the user, and till the arrival of acknowledgement how many times the alert message will be sent. The time interval between the two alert messages can also be taken from the rules by the JESS Rule Engine execution. Finally, the must send option for unacknowledged messages is important for routing of the alert messages.

4.3 Alert Manager

The alert manager is one of the key components for Saphire Alert System. This component contains the JADE Alert Agents which are proactive all the time and responsible for the alert messages. When the Saphire Alert System is started, a patient alert agent is created for each patient in the Saphire Alert System Database. Below in Figure 27, live agents can be seen. Each alert agent is responsible for the alert message requests for that patient; it receives the alert

message requests, analyzes and processes the alert message requests and then sends the alert message to the healthcare users by the help of the communication layer.

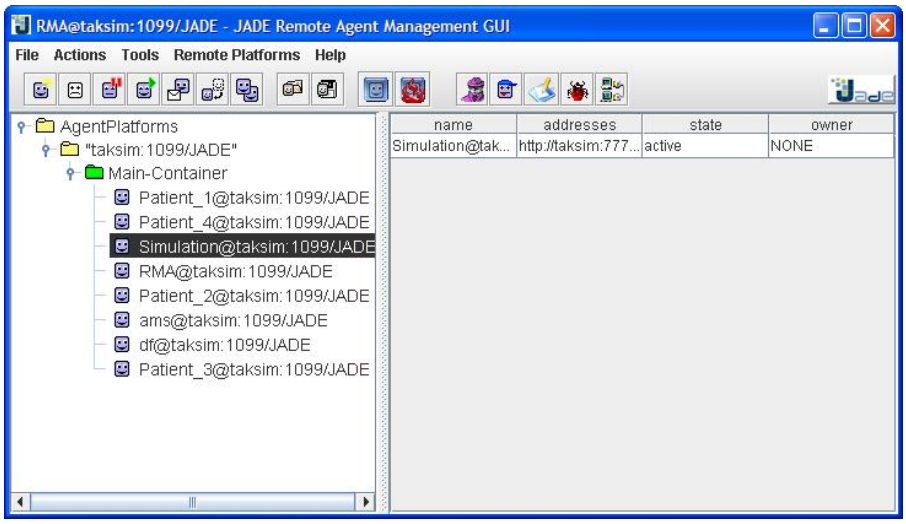


Figure 27 Saphire Alert System - JADE Platform (Agents)

For this component, Alert Agent Behaviors are developed which starts to work when an alert message arrives. For test purpose, a Simulation GUI has been developed which can be seen below in Figure 28. Behind that GUI, a simulation agent is working which sends the alert messages which are specified from the GUI by the tester.

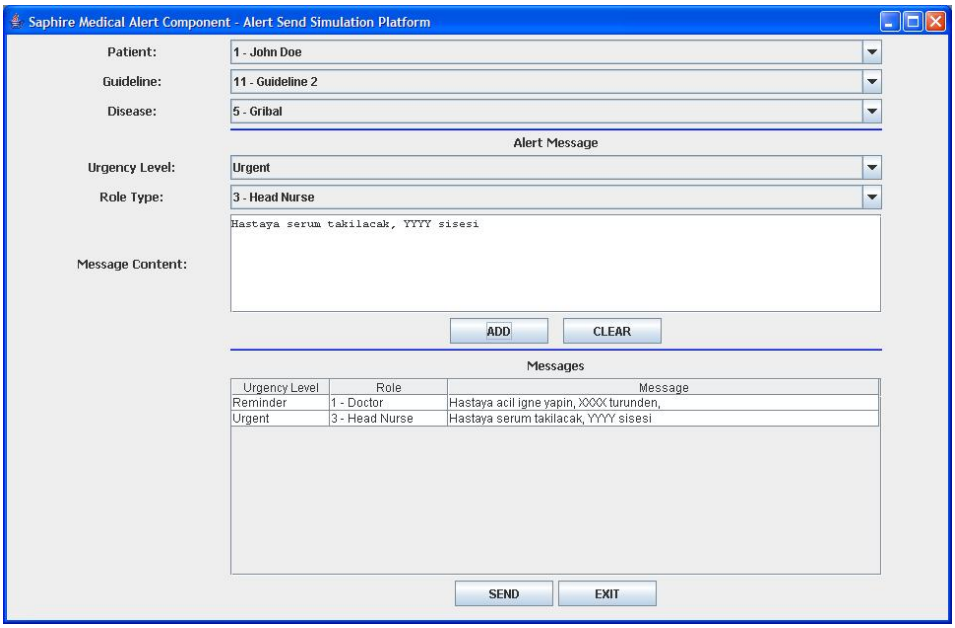


Figure 28 Saphire Alert System - Simulation GUI (Simulation Agent)

The communication between the simulation agent and other alert agents are achieved in ACL format. In Figure 29, general vocabulary of alert agent ontology can be seen. In this ontology, there are four main attributes which are patient information, guideline information, disease information and messages. As in Figure 30, patient information, guideline information and disease information are stored as integers with their IDs. The message is a list with three attributes in each item in the array. In each item, the urgency level, the role which the alert message will be sent and the content of the alert message are transferred. Urgency level is represented with string such as “Critical”, “Urgent” and etc. The role id is an integer and the content of the alert message is stored as string.

```
// The name identifying this ontology
public static final String ONTOLOGY_NAME = "Alert-Agent-Ontology";

// VOCABULARY

public static final String AlertMessage = "AlertMessage";
public static final String AlertMessage_PATIENT = "patient";
public static final String AlertMessage_GUIDELINE = "guideline";
public static final String AlertMessage_DISEASE = "disease";
public static final String AlertMessage_MESSAGES = "messages";

public static final String MESSAGE = "message";
public static final String MESSAGE_URGENCY = "urgency";
public static final String MESSAGE_ROLE = "role";
public static final String MESSAGE_CONTENT = "content";
```

Figure 29 Alert Agent Ontology – Vocabulary

```
// Structure of the schema for the AlertMessage Concept
ConceptSchema cs = (ConceptSchema) getSchema(AlertMessage);
cs.add(AlertMessage_PATIENT, (PrimitiveSchema) getSchema(BasicOntology.INTEGER));
cs.add(AlertMessage_GUIDELINE, (PrimitiveSchema) getSchema(BasicOntology.INTEGER));
cs.add(AlertMessage_DISEASE, (PrimitiveSchema) getSchema(BasicOntology.INTEGER));
cs.add(AlertMessage_MESSAGES, (ConceptSchema) getSchema(MESSAGE), 1, ObjectSchema.UNLIMITED);

// Structure of the schema for the MESSAGE concept
cs = (ConceptSchema) getSchema(MESSAGE);
cs.add(MESSAGE_URGENCY, (PrimitiveSchema) getSchema(BasicOntology.STRING));
cs.add(MESSAGE_ROLE, (PrimitiveSchema) getSchema(BasicOntology.INTEGER));
cs.add(MESSAGE_CONTENT, (PrimitiveSchema) getSchema(BasicOntology.STRING));
```

Figure 30 Alert Agent Ontology – Content

As defined before, the patient alert agents are proactively alive and waiting for ACL messages from the Saphire System which is simulated by the simulation agent. After receiving the alert message request in ACL format, the alert agent opens it and structures an agent behaviour for each alert message requests in the list. The patient, guideline and disease information is unique for the alert message requests in the list but the urgency level, role of the healthcare user who is concerned with and the message content can vary. The cyclic behaviour is waiting to receive the alert message requests and after the arrival of the message requests, the realization of the alert messages is achieved by the help of Saphire Alert System Database and Rules.

First of all, the assigned healthcare users are determined from the patient-guideline pairs whose patient data is contained in the alert message request. In the alert message request list, there is only the generic role id which represents

assistant doctors, head nurses, patient relatives and etc. The responsible healthcare user can be changed with assignments of the healthcare administrator. Before creating the agent behaviour which sends the alert messages with the help of communication layer and follows for acknowledgements and routings if necessary, the rules are executed for two purposes; changing the urgency level for the disease type, determining the communication details of the healthcare users with acknowledgement and must send specifications.

The patient alert agent retrieves the related information for the urgency level change rules based on the disease type. The rule-templates are constructed and loaded to the JESS Rule Engine with the fact that is on hand by the arrived alert message requests. After the run of the JESS Rule Engine, patient alert agent can obtain any changes in the urgency level of the alert messages. The second rule is processed in a similar way, the rule-templates are filled with data from the Saphire Alert System Database which will help to determine the contact type, contact number, acknowledgement request, number of attempt till the acknowledgement, time interval between each attempt and must send option for the routing of unacknowledged alert messages.

The alert agent behaviour is created with all these data which is a simple behaviour but will execute n times with m seconds interval if the alert message is required to get acknowledgement from the healthcare user. This alert agent behaviour is created for each alert messages and run in parallel. If the alert message needs acknowledgement where this information can be obtained by rule execution, the behaviour is executed till the acknowledgement is received, additionally, if the must option is specified and the acknowledgement cannot be received, the routing mechanism will be run by killing the current agent behaviour just after creating a new alert agent behaviour for routing the alert message to the permitted healthcare user. All these processes can be visualized better with an example; we have an alert message which needs acknowledgement and must send option is specified. As the rules tell us, the acknowledgement is waited till the end of three attempts with 120 seconds

interval. With all these information, the alert behaviour is created and the first alert message is sent with the specified communication channel. For 120 seconds, the acknowledgement is waited which is a confirmation e-mail in e-mail communication, GSM operator acknowledgement in SMS and user response in MSN Messenger. If the acknowledgement is not received, the same alert message is resent to the healthcare user and the same process is repeated three times which is specified by the rules. All these actions are logged with all the details (alert message id, patient, guideline, time stamps, etc) to the Saphire Alert System Database for further inspections. With the specified must send option, the alert agent behaviour understands that this alert message has a high importance and should be sent even if the main responsible healthcare user cannot be reached. The alert agent behaviour obtains the routing information such as which healthcare users are the secondary responsible of the alert message. With the same order in the rule execution and clarification of the details, a new alert agent behaviour is created for routing of the alert messages and the previous alert message is killed. The created alert agent behaviour for routing operates within the same manner; sends and follows the alert messages.

4.4 Communication Layer

The communication layer has an important role in the Saphire Alert System. This layer acts as the communication center of the system and the structured alert messages are sent with this component. As described below, the patient alert agents form the outgoing alert messages and it sends these alert messages by communication layer. The communication layer can check the acknowledgement of the sent alert messages additionally. The general requirements of the Saphire Alert System enforce the need to check the acknowledgements of the alert messages.

The Saphire Alert System – Communication Layer supports three types of communication channel in principal; e-mail messaging, SMS messaging and instant Internet messaging by MSN. These communication channels are selected

because of the high usage in the domain and less cost, only the SMS needs some payment while sending which is approximately 0.075 YTL for each SMS. The security and privacy issues are important while implementing the communication layer. SMS messaging and MSN Instant messaging have internal protocols for security and privacy but for e-mail messaging private-public key security infrastructure is used with globally recognized certificates. The details of the encryption mechanism used in mailing can be found in the succeeding sub section.

4.4.1 Secure e-mail Messaging

The e-mail messaging is one of the most important communication channels for the Saphire Alert System. Everyone has an e-mail address for both personal usage and also as a result of a company policy to stay connected over the Internet. Although you need Internet connection to receive your e-mail, e-mail sending is almost free and there is no limitation for the amount of data that can be transmitted by e-mail.

The Saphire Alert System is concerned with the security and privacy issue for the e-mail communication channel. For this purpose, a certificate based private-public key mechanism for e-mail communication channel has been deployed. Before the registration of the healthcare user to the Saphire Alert System, it is needed to deliver the public key for each e-mail address that the user will use because all the e-mails are encrypted with the specific public keys of the healthcare users and only the owner of the private key which matches with that public key, can open and read the e-mail. For all these encryptions, ASPENCRYPT Library [10] is used which is utilized with the .NET platform. The e-mail sending operation is utilized to the Saphire Alert System with a .NET Web Service from which both .NET platform and agents can access it. All these processes start with the healthcare user obtaining a specific certificate for his/her use. The site below is used to get certificates which are in the home page of ASPENCRYPT Library. By this web page, the healthcare user can install a private key to his/her system easily.

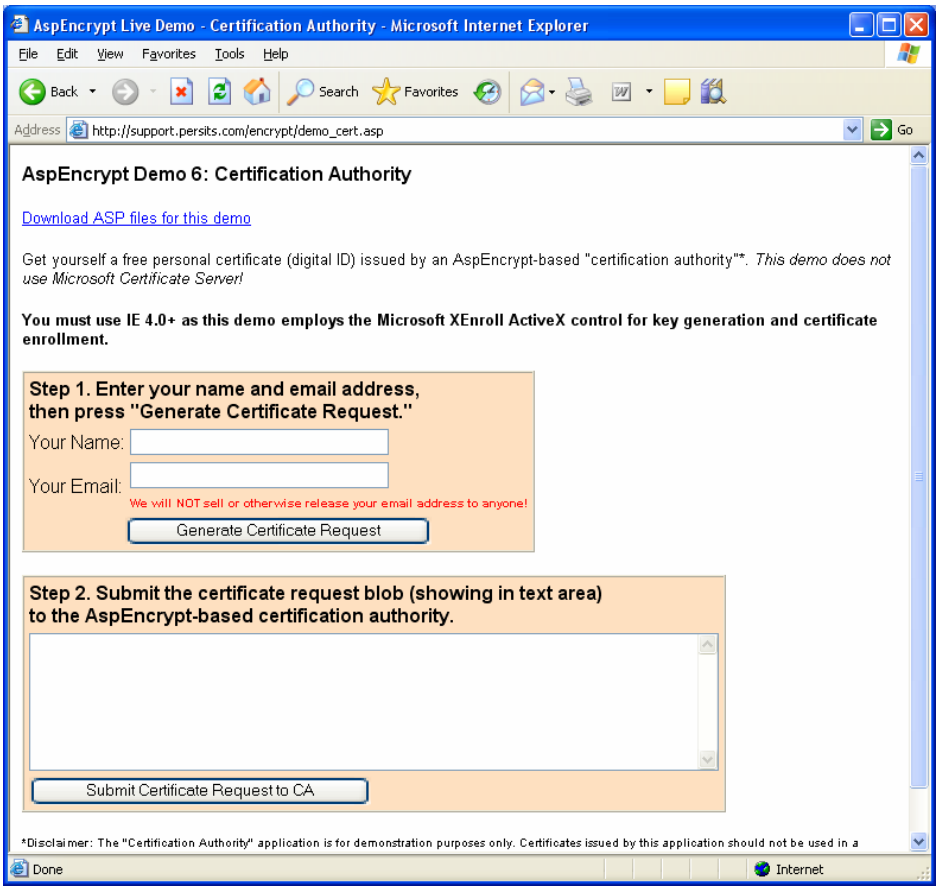


Figure 31 Certification Authority - Generate Certificate Request

After installing the certificate, all the available certificates can be viewed using Internet Explorer as in Figure 32. By the window below, the user can export the public key which is needed by the Saphire Alert System. The public key can be written to a file with CER extension in the format of DER encoded binary X.509. The export wizard can be seen in Figure 33.

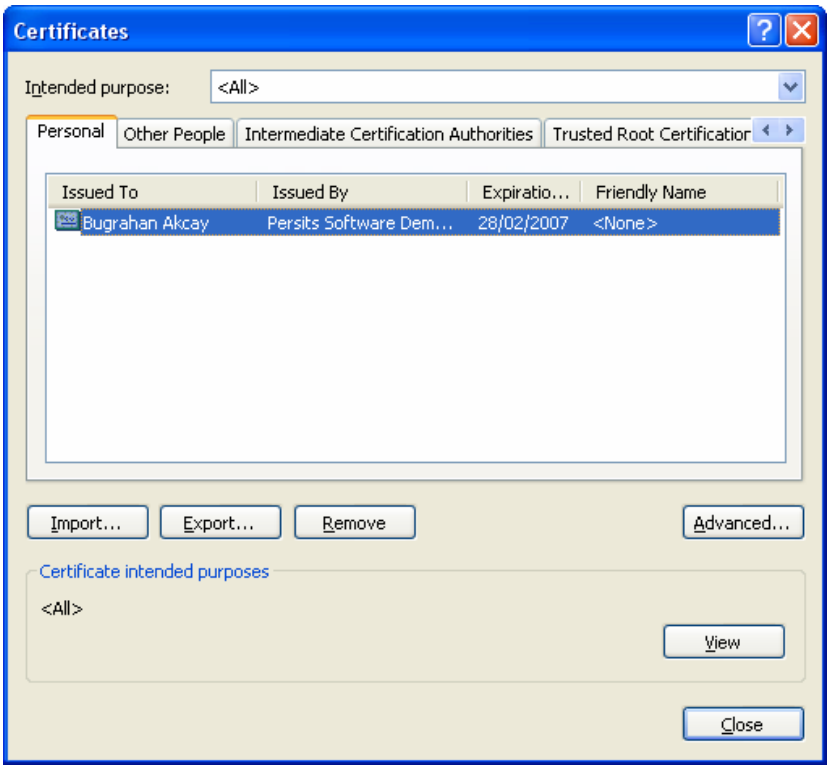


Figure 32 Certificates

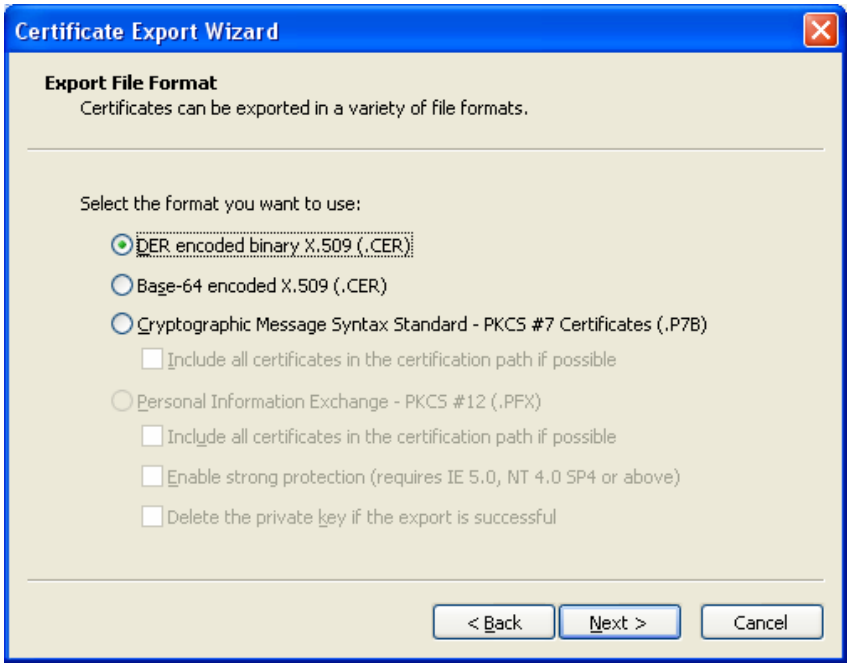


Figure 33 Public Key - Certificate Export

After obtaining the CER certificate file, the Saphire Alert System uses it to encrypt the alert message e-mail. The alert message e-mail is sent with a unique message id in the subject part of the e-mail which can be seen in Figure 34. Also it is located the urgency level, patient information and guideline information in the subject part of the e-mail. The content of the alert message is located in the e-mail body and in the bottom part extra information can be found if the alert message needs acknowledgement. If the alert message needs acknowledgement, the recipient should press reply and then send for the acknowledgement.

The Saphire Alert System uses sapals@srdc.metu.edu.tr e-mail address with the "Saphire Alert System" front name and the acknowledgements are sent to that e-mail address. The alert patient agent checks acknowledgement e-mail using POP3 protocol. As each alert message has a unique message id, the subject parts of the e-mails which are in the Saphire Alert System e-mail inbox are looked for the needed message id.

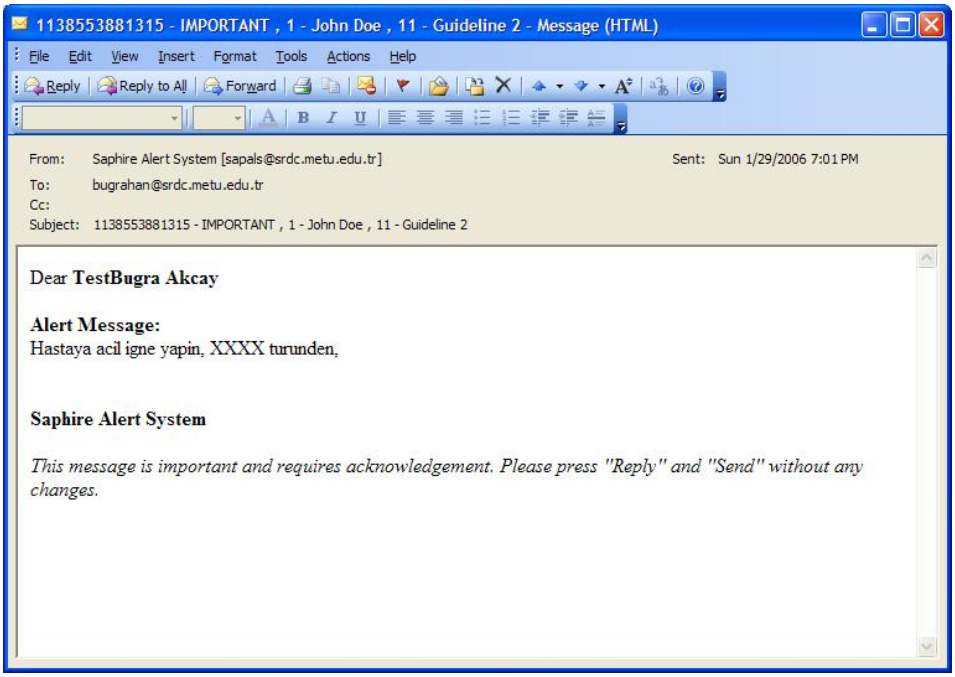


Figure 34 Alert Message e-mail

4.4.2 SMS Messaging

Mobile Phones have a key place in our lives. Most of us carry the mobile phones for 24 hours a day. In the healthcare domain where the urgency situations take place more often, the healthcare actors are mostly bounded to their mobile phones to keep up with the emergency situations. SMS is one of the simplest but useful standards for mobile phone communication. Saphire Alert System utilizes SMS messaging which is a fast and high delivery percentage communication channel. It has some cost which is within the limits for a domain such as healthcare.

Saphire Alert System can send SMS messages to healthcare users in a similar way as of e-mail messaging. For SMS sending and acknowledgement controls, Saphire Alert System uses a GSM Gateway whose URL is http://gateway.smsexplorer.net/com.mobilus. The registration of the Saphire Alert System has been done which is required to send SMS from the gateway. The SMS sending is accomplished by HTTP POST to the gateway URL. The SMS gateway offers a service to prepare messages in XML formats an example which can be found below.

```
<MainmsgBody>
        <UserName>saphire_alert_system_username</UserName>
        <PassWord>saphire_alert_system_password</PassWord>
        <Action>0</Action>
        <Mesgbody>message_content</Mesgbody>
        <Numbers>contact_number</Numbers>
        <Originator>SAPHIRE</Originator>
</MainmsgBody>
```

The action ‘0’ matches with SMS sending for the gateway; the message body and the contact number are provided within the related tags. The SMS gateway offers to send messages with the name of “SAPHIRE” which is stated in the Originator tag. After doing a HTTP POST to the specified URL, the gateway returns a unique id for the sent SMS message, where this unique id will be used for the follow-up of the SMS.

The acknowledgement operation is done with the help of SMS gateway. As there is a unique id for the sent SMS message, the gateway can be queried for the status of the message. The querying is done as in the way of SMS sending. The XML is structured which can be seen below and sent through HTTP POST.

```
<MainReportRoot>
        <UserName>saphire_alert_system_username</UserName>
        <PassWord>saphire_alert_system_password</PassWord>
        <Action>4</Action>
        <MsgID>message_id</MsgID>
</MainReportRoot>
```

The action number '4' is used for reporting purpose and message id is also needed for querying which will return a status number as a result. This status number tells if the SMS message has been sent, is in the queue or could not been sent. With this status number, alert agent behavior can decide whether to finalize the behavior or resend the SMS message again.

4.4.3 MSN Instant Messaging

Instant messaging gets involved in our Internet lives by different tools; MSN Messenger, Yahoo Messenger, Skype, ICQ and so on. In the Saphire Alert System, it is required to utilize this communication channel to reach the healthcare stakeholders. Instant messaging offers both free and fast communication over the Internet. For the Saphire Alert System, it has been chosen MSN Messenger which is used by millions of Internet users.

The Saphire Alert System e-mail address has been registered to the MSN system, sapals@srdc.metu.edu.tr where the MSN messages are sent with this user id. For all the MSN messaging operations, MSNBot library [11] is used and it is a JAVA library for code-based MSN logins, sending instant message to a healthcare user in the Saphire Alert System MSN list. In the Figure 35, an MSN message which is sent by the Saphire Alert System can be seen. The alert

message needs acknowledgement so it warns the healthcare user by “After you read the message please confirm by writing an answer”.

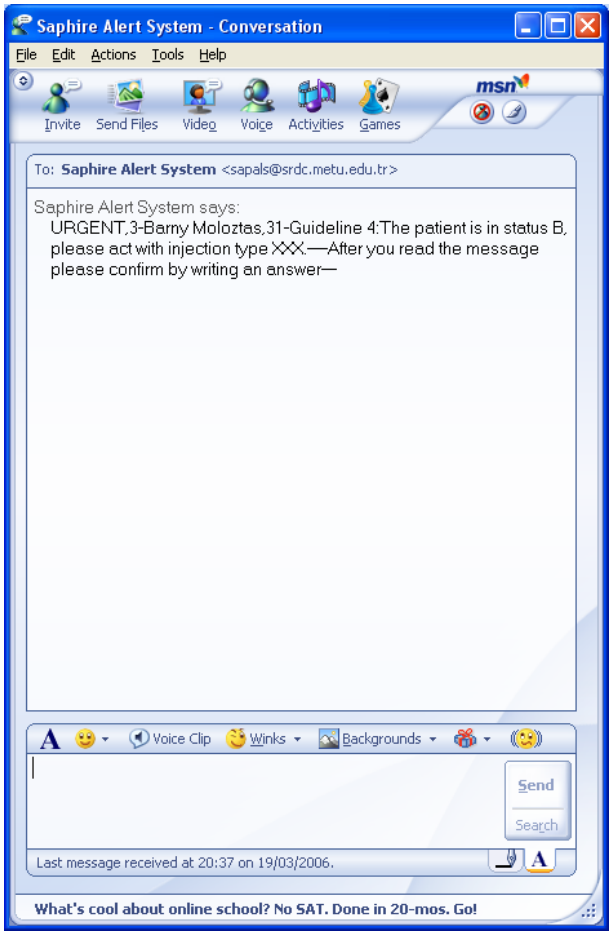


Figure 35 MSN Instant Messaging by Saphire Alert System

Any response from the healthcare user is counted as acknowledgement and the MSN Messaging classes detect the responses from the healthcare user. In the Figure 36, the acknowledgement and the auto-response from the Saphire Alert System can be seen. The instant messaging facility adds fast, popular and free communication way to the Saphire Alert System.

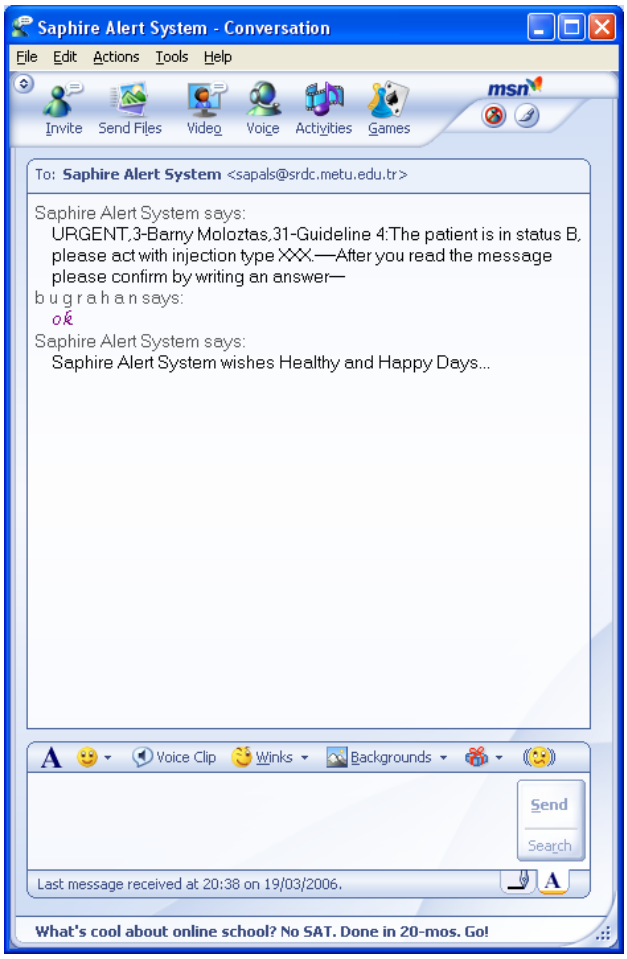


Figure 36 MSN Instant Messaging - Response from Healthcare User

4.5 Alert Data Model

This component covers all the Saphire Alert System and mainly is a meta-component. The overall data, information and knowledge are tried to be analyzed, designed and covered with this component. The alert data model has high interaction and dependency with other components because the realizations of all the data models are achieved by other components. Below it can be found the main items in the alert data model;

- ***Urgency Levels***; Urgent, Critical, Reminder, …
- ***Communication Systems***; e-mail, SMS, Instant Messaging, …
- ***Diseases and Symptoms***; Cardiovascular, Fatigue, Hypertension, Pain, …

- ***Users***; Healthcare Users, Healthcare Administrators
- ***Roles***; Healthcare Provider, Physician, Nurse, Patient, …
- ***Permissions***; Routing Mechanism

All these concepts and data models are tried to be realized by mainly Saphire Alert System Databases and Rules. As described in the Section 4.2, the Saphire Alert System Database is designed to cover all these meta-data. The patients, healthcare users, healthcare roles, disease, rules data, alert messages are all stored with the tables in Saphire Alert System Database. Additionally, JESS Rules also help to store the alert data model by meta-rules and facts. In addition to all this, other components such as Saphire Alert System Web-based User Interface cooperates with alert data model by warnings, user messages, functionalities which are offered by the component.

CHAPTER V

CONCLUSION

In this work, an agent-based alert system is developed for intelligent healthcare monitoring. All these activities are achieved within the scope of a European Commission R&D Project, SAPHIRE [18]. The intelligent healthcare monitoring from remote location is a hot topic, since Europe is getting older. The Saphire project aims to monitor the patients by sensors and clinical guidelines in their own location where an emergency situation is detected and the related information is sent to the healthcare stakeholders.

The developed agent-based alert system is a component of whole Saphire System where the alert messages are transmitted to the healthcare users; doctors, nurses, patient relatives. The alert system is structured over a multi-agent platform where an agent is assigned to each patient to follow his/her alert messages. The intelligence is added to the alert system by rules; which alert message is sent to whom by which contact number is determined by the agents at run-time. The alert system provides a web-based user interface where the healthcare users can manage their patient-guidelines, their alert message receiving properties, access logs and other options. Additionally, agent-based alert system supports various popular communication channels; e-mail messaging, SMS and MSN Instant messaging which increase the probability of access to the healthcare user. Another important aspect of the agent-based alert system is proposing acknowledgement option for the alert messages; it is also provided to be re-routed the alert message to other healthcare users who have the permissions.

The R&D activities within the scope of Saphire Project will continue and agent-based alert system can evolve with that needs but it has a high maturity which is ready to integrate with the whole Saphire System.

REFERENCES

[1] JADE - Java Agent DEvelopment Framework, http://jade.tilab.com/ , May 2006

[2] JESS – The Rule Engine for JAVA Platform, http://www.jessrules.com/ , May 2006

[3] RuleML – Rule Markup Language - http://www.ruleml.org/ , May 2006

[4] JSR-000094 Java Rule Engine API - http://www.jcp.org/en/jsr/detail?id=094 , May 2006

[5] Mandarax RuleML - http://mandarax.sourceforge.net , May 2006

[6] OO jDREW - www.jdrew.org/oojdrew/ , May 2006

[7] SWRL - Semantic Web Rule Language - http://www.daml.org/2003/11/swrl/ , May 2006

[8] OWL DL - http://www.w3.org/TR/owl-guide/ , May 2006

[9] OWL Lite - http://www.w3.org/TR/owl-guide/ , May 2006

[10] ASPENCRYPT Library - http://www.aspencrypt.com , May 2006

[11] MSNBot Library - http://www.mr-f.org/doc/org/mrf/MSNBot , May 2006

[12] D. Jung and A. Hinze. A Mobile Alerting System for the Support of Patients with Chronic Conditions. In Proceedings of the First European Conference on Mobile Government (EURO mGOV) 2005, pp. 264-274, Brighton, UK, July 10–12 2005.

[13] A. Moreno, D. Riano and A. Valls. Agent-based Alarm Management in a Palliative Care Unit, PalliaSys (TIC2003-07936, Spanish Secience and Technology Ministry), the research network AgentCities.ES (TIC2001-5108-E, Spanish Science and Technology Ministry)

[14] E. Kafeza, D.K.W. Chiu and S.C. Cheung. Alerts in Mobile Healthcare Applications, IEEE Transactions on Information Technology in Biomedicine, 8(2):173-181, June 2004.

[15] Wagner MM, Tsul FC, Pike J, Pike L. Design of a clinical notification system. Proc AMIA Symp 1999:989-93.

[16] Chen, H. T., Ma, W. C., and Liou, D. M. Design and implementation of a real-time clinical alerting system for intensive care unit. In Procs AMIA Annual Symposium (San Antonio, USA, November 9-13, 2002). 131-135.

[17] Dickson K.W. Chiu, Benny W. C. Kwok, Ray L. S. Wong, S.C. Cheung, Eleanna Kafeza, Marina Kafeza, "Alerts for Healthcare Process and Data Integration,"

hicss, p. 60146, Proceedings of the 37th Annual Hawaii International Conference on System Sciences (HICSS'04) - Track 6, 2004.

[18] IST-4-027074-STP SAPHIRE: Intelligent Healthcare Monitoring based on Semantic Interoperability Platform, http://www.srdc.metu.edu.tr/webpage/projects/saphire/ , May 2006

[19] National Guideline Clearinghouse™ http://www.guideline.gov/ , May 2006

[20] IST-1-002103-STP ARTEMIS: A Semantic Web Service-based P2P Infrastructure for the Interoperability of Medical Information Systems http://www.srdc.metu.edu.tr/webpage/projects/artemis/ , May 2006

[21] M. Knapik, and J. Johnson. Developing Intelligent Agents for Distributed Systems, McGraw-Hill, 1998.

[22] Sun Microsystems's Java language, http://java.sun.com/ , May 2006

[23] Agent Communication Language (ACL), http://www.fipa.org/repository/aclspecs.html , May 2006

[24] Foundation for Intelligent Physical Agents (FIPA), http://www.fipa.org/ , May 2006