Distributed Architectural Framework For Patient Records Management

M. Grammatikou, F. Stamatelopoulos, B. Maglaris
Network Management & Optimal Design Laboratory (NETMODE)
Computer Science Division - Electrical & Computer Engineering Department
National Technical University of Athens (NTUA)
Zografou, 15780, Athens, Greece
{mary,fotis,maglaris}@netmode.ntua.gr

Abstract: *We present a distributed architectural framework for Healthcare Information Systems that implements patient record management in a distributed regional healthcare environment. Distribution is handled through the introduction of the Roaming Electronic Healthcare Record and the use of local caching and incremental update of a global index. We discuss efficiency, scalability and security issues and we present a proof of concept implementation based on middleware (CORBA) and web-based technologies. Finally, we present an SNMP-based management framework that aims to integrate the monitoring and control of the proposed distributed system with conventional network and system management processes and tools.*

Keywords:Healthcare Information Systems, Distributed Architectures, Middleware, Internet Technologies, Medical Database Management.

1 Introduction - Motivation

Databases and information retrieval technology changed the way medical records are managed, by providing remote and timely access to huge medical archives. However, the majority of medical information systems currently in operation suffer from their centralized nature that fails to satisfy the distributed requirements of a regional or nation-wide health care system. The main drive of the research work presented in this paper, emanated from the requirements analysis and the result evaluation of various medical informatics projects that our group participated in. Our involvement in these R&D activities made us realize the need for a distributed approach in medical/health information systems, capable of handling volumes of medical data over wide area networks with improved performance, fault tolerance and security. The starting point of this work was the user requirements analysis and the development of a health care workflow model within the ITHACA project (EU Telematics HC 1029) [3], as well as our recent efforts in designing architectures that satisfy the following needs:

- Location-transparent and efficient access to the Electronic Healthcare Record (EHR) in a wide area scale.
- Secure data transfer and distributed access to medical records.

In [6] we presented the conceptual design of a distributed healthcare architecture that supports patient case management and relies on the distribution of the EHR storage. In this paper, we extend the proposed architecture with functionality that improves fault tolerance, performance and scalability. We present a proof of concept implementation that applies middleware techniques and Internet/Intranet technologies for implementing healthcare workflow management [7] in a distributed operating environment.

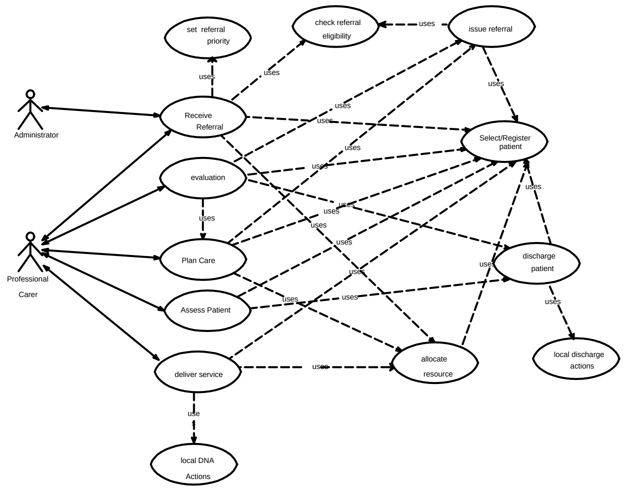

Figure 1: The Supported Workflow Model

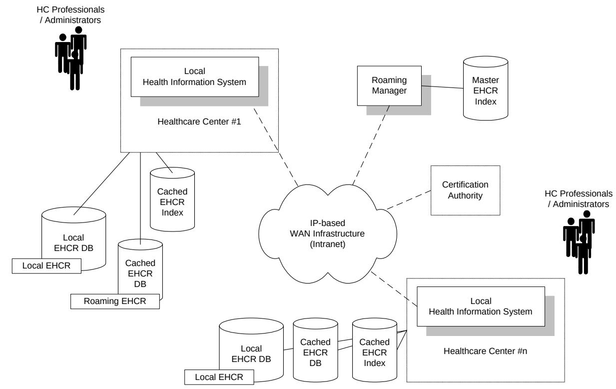

Figure 2: Conceptual Architecture Outline

2 Architectural Framework

2.1 Healthcare Workflow Model

The proposed architecture aims to assist the typical healthcare workflow model, which includes patient assessment, care planning, delivery of appropriate healthcare services and evaluation of care outcomes. Figure 1 provides an overview of such a workflow (analyzed in [6]). The patient may enter through any Healthcare Center (HC), change workflow states within multiple HCs and exit the workflow in a different HC.

2.2 Architectural Overview

Figure 2 presents the conceptual outline of the proposed architecture. All HCs are equipped with a local healthcare information system (HIS), and they are interconnected via an IP-based WAN (Healthcare Intranet). Each HIS implements the specific workflow model and maintains a database for storing and managing locally registered EHRs (Electronic Healthcare Records). The key feature of the proposed distributed approach is the functionality introduced by the concept of the Roaming EHR (R-EHR): the EHR migrates to the appropriate HC in order to follow the patient visits to different HCs within the regional healthcare system. In order to implement the R-EHR each HIS maintains an additional database for storing the R-EHR images (cached copies). The Roaming Manager (RM) is a coordinating entity that maintains the global directory/index of all the EHRs and assists the HISs during EHR location identification and data migration. This directory maintains the location of all master and cached copies of all records, including timestamps of last update and other administrative information. A cached copy of the global index is maintained at the local HIS and it is incrementally updated, either periodically or during RM queries; highly utilised HISs that frequently query the RM should update their index images periodically, however, HISs that do not query the RM often should defer the update up to the last minute. Fine-tuning is required in order to achieve the optimal trade-off between performance and network traffic.

The Certification Authority (CA) is also a centralised entity within the HC Intranet that is responsible for issuing certificates and ensuring party authentication, as described in [1]. The CA assigns digital certificates to all entities within the architecture, in order to support digital ”signing” of RM-to-HIS and HIS-to-HIS interaction. The use of the digital certificate mechanism assures non-repudiation, safeguards server identification and protects against masquerading.

2.2.1 Caching, Roaming and Update Policies

The Roaming Manager is the responsible entity for initiating and coordinating:

- *Query redirection.* The RM maintains and updates the Master Index database, i.e. the directory that tracks the location of all master copies and the corresponding cached images within the proposed architecture. The HIS queries the RM for every patient that cannot be matched by a locally stored record. The RM locates the master copy and redirects the HIS query accordingly.

- *Cached image invalidation - update.* If a local copy (R-EHR) exists locally, the HIS consults the RM for verifying its validity (ensure that the master copy has not been changed); invalidated images will be updated by redirecting the query to the appropriate HIS with an up-to-date copy of required record. Incremental updates can be used in order to reduce traffic during updates.

- *EHR roaming and migration.* The RM coordinates and monitors the roaming and migration of the patient records. Triggered by query redirection or cached image invalidation, the HIS contacts the appropriate remote HIS, retrieves the R-EHR and stores the updated information in its local database. The record will finally migrate to the site that the patient most frequently visits. RM Master Index is updated upon all successful image installation, update or migration of an R-EHR.

Figure 3 outlines the proposed HIS internal structure and illustrates typical operation: Jim has his record registered in the local HIS (HC#n). When Jim enters a remote site (e.g., HC#1), the remote HIS will identify the location of Jims EHR through the locally cached index (a query for possible updates is first sent to the RM). It will then retrieve it directly into the local EHR cache (R-EHR) and the RM will

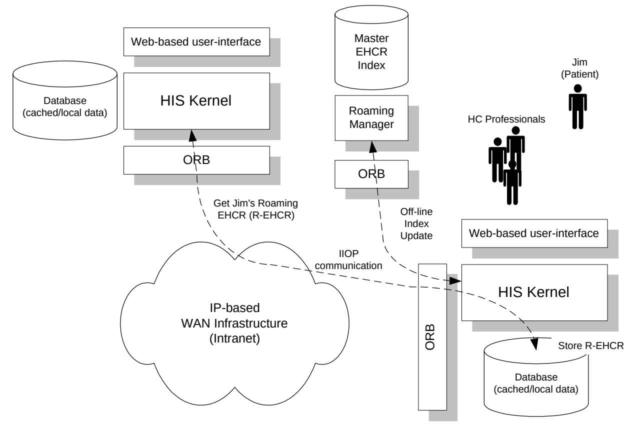

Figure 3: Example of Operation (Middleware-based approach)

be notified that a copy of Jims record is stored in HC#1. After the local (roaming) copy of his record is installed, Jim will enter the system workflow. The cached R-EHR will be deleted after a specific time period, unless Jim visits HC#1 again. If Jim persists in visiting the new site beyond a specific time period, the cached record will be designated as the new master record (R-EHR permanently migrates to HC#1), the old master record in HC#n will be considered a copy and the Roaming Manager will be notified accordingly.

2.2.2 Security Issues

(a) *User authentication.* The local HIS defines a set of user roles with associated permissions and access rights. User authentication is critical and it is handled at the local HIS level through the typical username/password mechanism or digital certificates.
(b) *Server authentication.* Digital certificates are used for authenticating all entities during the interaction and for protecting against masquerading. Certificates are issued and managed by the central CA that supports registration, naming, directory services, and key management [2].
(c) *Encryption of entity interaction and network communications.* For additional security against eavesdropping, encryption should be

applied on all communication channels. Although many approaches are available, SSL encryption over IIOP / HTTP connections is an attractive solution.

2.2.3 Fault Tolerance

The proposed framework provides a limited level of fault tolerance based on the use of multiple copies. In the event of failure of the master copy site, the RM can locate the most recent and valid copy of the patient record (R-EHR) and redirect the query to the corresponding site. Although this approach provides a level of fault tolerance, in many cases, there will be no cached copies. Fault tolerance can be more effectively implemented through the introduction of redundancy in the storage of the EHR master copies; e.g. the EHR is maintained in two HISs, the local HIS that the patient is registered and one HIS selected by the RM according to a load-balancing algorithm (the RM uses its directory so that redundant storage is equally distributed to all HISs in its domain).

2.2.4 Scalability Issues

The centralized nature of the RM may cause a bottleneck effect in high utilization environments, minimizing overall scalability of the proposed architecture. Figure 4 presents a distributed alternative approach that yields higher scalability: in this case HISs are divided in multiple domains according to geographical, organizational or other regional criteria; each domain is assigned to a regional RM (RRM). As outlined in the figure, query redirection is coordinated by cooperating RRMs in a transparent way, since the HIS interacts only with his local RRM. In this case, Master Index updates must be re-routed by the local RRM to the appropriate RRM. This scheme can be expanded to a hierarchy of RMs in order to handle wide-area or international scale.

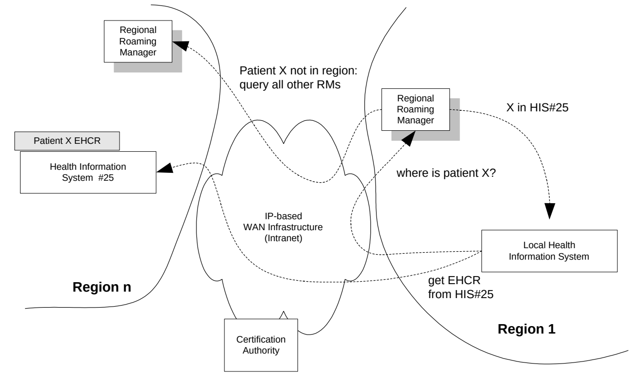

Figure 4: Multiple-Region Scenario

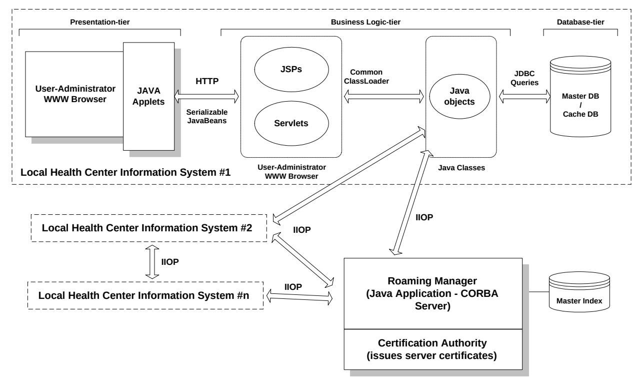

Figure 5: Pilot Implementation Details

3 Proof of Concept

In order to provide a test-bed for testing and fine-tuning the overall architecture, as well as produce the "proof of concept" of our design, we developed a pilot implementation of the Health Information System and Roaming Manager described above.

3.1 Implementation of a Pilot Architecture

We adopted a three-tier architecture and we based our implementation on web-based user interfaces, CORBA and Java technologies. Figure 5 sketches the outline of the pilot architecture we implemented.

The HIS implementation consists of the typical three tiers:

- The *presentation tier* implements the user interface and relies on HTML static data and Java applets and Java Server Pages (JSPs). This approach simplifies software maintenance (new forms and user interaction functions are easily added) and allows the use of inexpensive client hardware (low resources are needed for running a web browser).

- The *business logic tier* implements the largest part of the workflow, as well as all the caching and handling of roaming records. It is implemented through the use of Java Servlets and Javabeans.

- The *database tier* consists of typical relational database management systems that handle all data storage and retrieval. Alternatively, we considered the use of a back-end LDAP directory server for implementing the Roaming Manager directory services (master index).

3.2 Management Framework

Although the distributed architecture that we designed and pilot implemented is capable of meeting the goals of our work, it also introduces complexity (as all distributed systems do) and requires significant effort for administration and maintenance. The IETF management framework provides a de facto standard for network and system management that has been proven effective for application and service management as well as distributed enterprise management ([8],[10],[11]). Figure 6 presents a management framework that we implemented for the proposed architecture. We designed and implemented two SNMPv2 Management Information Base structures (the HIS MIB and the RM MIB) for monitoring the status and usage of the HISs and the RM. We also developed a distributed management application (Java-based implementation) for remote management of the proposed architecture. However, any commercial SNMP management tool can be used to integrate the

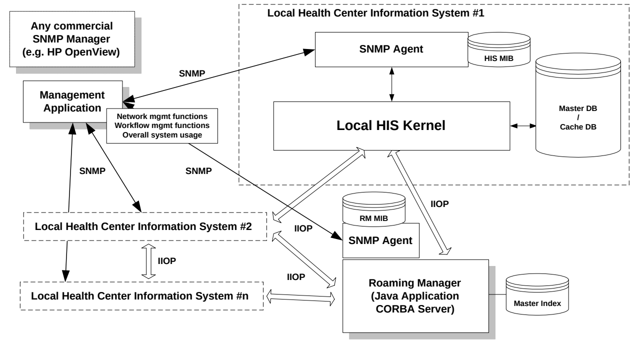

Figure 6: Management Framework Pilot Implementation

management of our system into the traditional network and system operation & management process.

4 Synopsis

We presented a distributed architectural framework for supporting Healthcare systems on a regional or national level and described the basic concepts based on the introduction of the roaming record (R-EHR) that addresses performance as well as security, scalability and reliability issues. We outlined a specific implementation that relies on middleware-based and web-based technologies, although the conceptual architecture is also open to other middleware approaches (like HL7 [5]). The proposed architecture was implemented as a proof of concept and the resulting pilot is currently being used as a test-bed for further experimentation with distributed architectural issues.

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