Incorporation of GIS, Grid Computing and RFID into National Health Information Federation toward Seamless Infectious Disaster Management

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Received 15 January2008; Revised 30 April 2008; Accepted 1 May 2008

Abstract. Several healthcare disasters have arisen in the past decade. The application requirements for such a system include effective, coordinated responses to disease and injury, accurate surveillance of area hospitals and efficient management of clinical and research information. Based on the application requirements, this work describes a health information federation that monitors and detects national infectious events using GIS, RFID and grid computing technology. This system is fault-tolerant, highly secure, flexible and extensible. It has a low cost of deployment, and is designed for large-scale and quick responses. Owing to the federation nature of the network, no central server or data center needs to be built. To reinforce the responsiveness of the national health information federation, this work proposes a practical, tracking-based, spatially-aware, steady-to-use and flexible architecture, based on GIS and RFID, for developing successful infectious disaster management plans to tackle technical issues. The proposed architecture achieves a common understanding of spatial data and processes. Therefore, the proposed system can efficiently and effectively share, compare and federate yet integrate most local health information providers and results for more informed planning and better outcomes.

Keywords: Syndromic Surveillance, Geographic Information System (GIS), Grid, Radio Frequency Identification) Technology (RFID), Juxtapose (JXTA)

1 Introduction

Several outbreaks of disease in the past decade, such as the SARS epidemic of November 2002 to June 2003 [1], have had brought disaster to society worldwide, including healthcare practitioners, healthcare institutions and public works personnel [2]. To improve the management of such disasters in the future, much attention has been drawn on interoperability for a nationwide health information network [3]. The collection of a large mass of data with mass surveillance systems requires trade-offs between quick response and accuracy. The application requirements for such a system include effective, coordinated response to disease and injury, accurate surveillance of area hospitals and efficient management of clinical and research information.

Nationwide health information networks or federations can be extremely complicated, since they have to integrate geographically distributed healthcare providers and other units with distinct functions and mutual dependencies. This paper proposes an enhanced health information network to handle nature disasters resulting from mass outbreaks of disease. Based upon the application requirements, the proposed health information federation monitors and detects national infectious events with GIS, RFID and grid computing technology. This system is fault tolerant, highly secured, flexible and extensible, with a low entry effort and designed for a large-scale and quick response. The federated nature of the proposed system means that no central server or data center needs to be built.

To elevate the responsiveness of the national health information federation, this paper proposes a practical, tracking-based, spatial-aware, steady-to-use and flexible architecture, based on GIS and RFID, for developing successful infectious disaster management plans. The proposed architecture achieves a common understanding

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of spatial data and processes, thus enables the system to efficiently and effectively share, compare and federate yet integrate most of the local health information providers and results to accomplish more informed planning and better outcomes than conventional architectures.

The rest of this paper is organized as follows. The next section reviews existing infectious disaster control and syndromic surveillance systems, as applied to emergency response management in general. The following two sections introduce emerging technologies, and apply them to the proposed information federation architecture on infectious disaster management. Conclusions are drawn in the last section.

2 Infectious Disaster Control and Management Systems

A disaster is commonly defined as an emergency of high severity and magnitude, leading deaths, injuries, illness or property damage that cannot be effectively managed by applying routine procedures or resources [4]. A well-designed emergency management system involves a set of arrangements, procedures, resources, personnel and relations that can alleviate the impact of hazards, emergencies, and disasters [5]. Natural disasters such as floods, earthquakes, and hurricanes pose a greater risk to the public than other disaster events [4]. Since every disaster has different characteristics, emergency planners have to be prepared for many different disasters. We proposed an enhanced federated health information system for handling major disasters.

The World Health Organization (WHO) praised GPHIN (Global Public Health Intelligence Network) for its role in early detection of SARS. GPHIN provided some of the earliest alerts to the November outbreak in China [6]. GPHIN is part of WHOs Global Outbreak Alert and Response Network, developed and operated by Health Canada's Centre for Emergency Preparedness and Response. It is essentially an Internet crawler that specializes in locating news articles of unusual events relevant to public health [7]. GPHIN continually scans over 400 international sources for news of any outbreaks of 31 communicable diseases, as well as articles about natural disasters and drug-resistant pathogens, rather than relying on official reports from government sources.

Since epidemics propagate dynamically, many studies have reported the causes and consequent behavior patterns of infectious disease outbreak in various dynamics approaches [8, 9]. System dynamic modeling enables multiple political, environmental, social, and structural variables to be integrated into one model. A system dynamic models derives the behavior of all variables in a system, allowing policies to be tested repeatedly [10]. The system dynamics modeling methodology has been applied many times to the health sector, and proved itself in resolving complex, systemic issues [11-14].

Geographical information system (GIS) can be utilized to develop maps presenting the spatial distribution of infected areas, infected populations, and causes of infection which are important for the spatial and temporal dynamics of transmission of infectious diseases [15]. Few studies have discussed the application of GIS and spatial analysis for dengue around the world [16]. Excellent health decision support systems have been built using GIS technology [17] and other emerging technologies, including Grid and RFID.

Spatial data analysis and mining have widespread applications. In a syndromic surveillance system, geographical data can be employed to discover local clusters of disease. Environmental health studies often rely on GIS software to map areas of potential exposure and geographical health issues, as well as to locate people in relation to these regions [18, 19]. Information obtained from long-term entomological and epidemiological surveillance an infected region can be manipulated and presented using spatial analysis tools available in GIS. This is important for predicting impending epidemics in order to facilitate limited resources in a cost-effective and efficient manner, and to control epidemics of infectious diseases.

Grid technologies are widely adopted in scientific and technical computing [20]. Grid technologies and infrastructures support the sharing and coordinated application of diverse resources in dynamic, distributed virtual organizations [21]. Geographically distributed components operated by distinct organizations with differing policies, of virtual computing systems can be integrated to form a health information federation. Grid federation is characterized as a set of heterogeneous systems federated over a wide-area network [22]. In contrast to the general Internet, such systems are generally interconnected by special high-speed, wide-area networks in order to obtain the required bandwidth for their applications. Any federated approach toward the creation of a health information network environment should be capable of providing uniform standards for accessing authentic, physician-generated information that is physically located in different clinical information systems [23].

While grid computing is a straightforward concept, the practical realization of grids poses a number of challenges. Security, heterogeneity, reliability, application composition, scheduling, and resource management are all important issues [24]. Grid computing makes extreme demands on distributed programming, because grids are typically large-scale systems that exploit wide-ranging networks comprising a variety of protocols and systems that may span organizational boundaries. We propose a health information federation architecture based on grid technologies. The proposed system elevates cross-platform federation without sacrificing flexibility, scalability, reliability or extensibility.

Natural disasters resulting from mass epidemic outbreaks have drawn much attention recently. In response to these events, the biomedical, public health, defense and intelligence communities are developing new approaches for real-time disease surveillance in an effort to augment current public health surveillance systems. The term “syndromic surveillance” refers to methods based on detection of clinical case features that are discernible before confirmed diagnoses [25]. In particular, ill persons may exhibit behavioral patterns, symptoms, signs or laboratory findings that can be tracked through a variety of data sources prior to the laboratory confirmation of an infectious disease. New information infrastructure and methods to support timely detection and monitoring, including the discipline of syndromic surveillance, are evolving rapidly [26, 27].

Rapid detection of outbreaks of disease requires immediate response to minimize effects on public health and other social factors. Public health departments routinely undertake surveillance of naturally occurring disease within the community, with the aim of early detection and treatment. An effective syndromic surveillance system can provide timely information to detect outbreak and adverse public health events, thus facilitating early intervention [28].

Syndromic surveillance data needs to be available and effective locally, regionally and nationally. Therefore, a common infrastructure that can be utilized at all levels of decision-making should be created. Such an infrastructure is likely to require a common communication vehicle for syndromic surveillance. Users should be able to query the resulting network of surveillance systems for information on all scales. This requires high levels of interoperability and data integration, including a common functional behavior.

The emergence of electronic healthcare data systems has led to the ability to monitor health data in near real-time, presenting a new opportunity to monitor the health status of the community. Implementing syndromic surveillance based on automated acquisition of clinical data requires both the development of secure, reliable information systems, and the use of those systems in public health practice. The rapid collection and dissemination of information, the sharing of that information and a comprehensive reporting mechanism could permit earlier intervention in outbreaks. Since the proposed system is sensitive to underlying changes in the data, it can detect outbreak signals quickly, thus mitigating the effects of large-scale outbreaks of disease.

The challenge created by global outbreaks of disease means that efficient monitoring devices in patient tracking are essential to the success of early intervention in epidemic surveillance. Early intervention can now be accomplished through emerging technologies. Wireless communication can support the widespread and instantaneous tracking of victims or resources through barcode or RFID systems. It can eliminate manual data entry, and increase the productivity of automated processes, even under difficult working environments. Radio frequency tags also may be attached to responding personnel, vehicles, equipment or supplies. RFID systems have a major advantage over handwritten or bar-code-based identification systems, Since they support the simultaneous collection of information from thousands of RF tagged persons or objects, and do not depend on line-of-sight contact between a receiver and a tag. Moreover, some RF systems allow data stored on RF tags to be updated or expanded (e.g., permitting the revision of triage scores on RF tags attached to individual victims). Additionally, RF-tagged victims or resources may be located via GIS to produce a real-time map of an entire population [29]. RFID technologies have been found to be more reliable and durable than bar codes in various levels application and functionality [30].

3 Proposed Integrated Information Infrastructure

A nationwide health information network would provide an effective means to access all available clinical information, at corporate, regional, national or even international levels, and to meet challenges posed by patient mobility and the fact that an individual’s health data may reside at many geographically dispersed information systems [31]. In addition to providing spatially distributed information, the system may be a valuable tool for basic and clinical research, medical decision making, epidemiology, evidence-based medicine and formulating public health policy. The major aim of such a system is to bring timely health information to, and aiding communication among, those making health decisions for themselves, their families, their patients and their communities [32, 33].

Very large-scale information systems are normally deployed as centralized or distributed architectures. In a centralized architecture, a single server is responsible for processing all user requests. Centralized architectures simplify administration and coordination of a service, and often require fewer resources. However, centralized architectures also have several disadvantages. A centralized server represents a bottleneck in processing that can delay response time. It may represent a single point of failure and a single point of attack for adversaries. Finally, even if the server is resourceful and available, the routing function provided by the communications layer may fail to provide a path from clients to the server [34].

Fig. 1 shows the proposed national health federation architecture integrated with RFID, GIS and grid computing. Each federated service serves as a gatekeeper to actual information providers. Federated syndromic surveillance service provides outbreak detection and mitigation services. A federated GIS atlas service provides map services.

A federated health record service provides medical records. A federated patient tracking repository service acts as a huge data warehouse containing massive data of RFID recordings. The health record and location are detected and tracked by RFID/grid Network Resources. All information is stored evenly in the Federated Patient Tracking Repository across the grid infrastructure. Each client can use any of the federated services introduced by a nearby service broker. The proposed architecture has four federated services.

The grid client presented in Fig. 1 need not be an end-user system, but could be an agent acting on its behalf. The system may consist of many such clients or agents, acting independently with no central control over the components shown. To make use of resources, a client first requests information sources located within service brokers to discover those resources needed to execute of a task. Multiple sources may need to be consulted to locate all the resources needed for a computation. Assuming that the discovery and allocation steps are successful, the client then sends the input data and executables, receiving a reference to the execution in return. These actions may be accomplished in several stages or as one consolidated action, depending on the nature and complexity of the task. The resource manager may need to update the information in the registry as resources are allocated, in order to permit reasonable bids for resource allocation from other clients. Finally, the client monitors execution of the task using the reference that it had previously received. It can retrieve the results, or be sent status of the task, as it progresses.

A service broker accesses static and dynamic information of resources. The broker has three major components, Local Information Registry (LIR), Global Resource Registry (GRR) and Lightweight Directory Access Protocol (LDAP) provider.

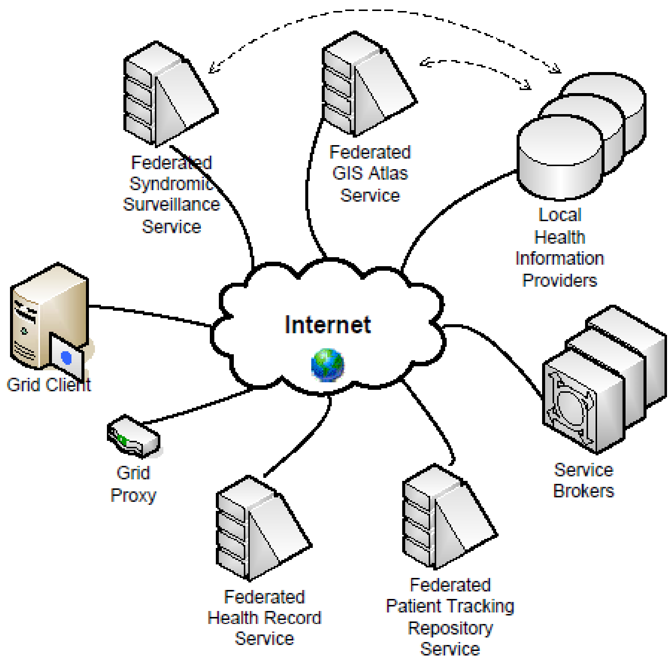

Fig. 1 An architecture for health information federation.

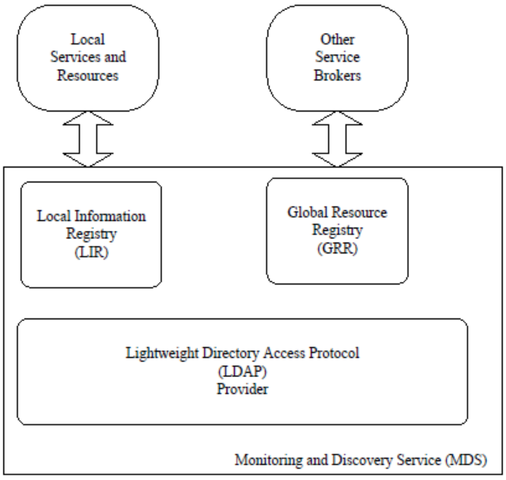

Fig. 2 The logical components of a service broker.

Fig. 2 illustrates the logical components of a service broker. This architecture has two registries and a service. The Monitoring and Discovery Service (MDS) acts as a gatekeeper to resources from outside of it. The Fig. depicts an example in which the local health information, collected by the RFID/Sensor Networks, is obtained by the information provider and passed to LIR. The LIR then registers its local information with the GRR, which also registers with another GRR. Federated service clients can obtain the resource information directly from LIR for local resources, or from a GRR for grid-wide resources. An LDAP in the federated services provides the decentralized maintenance of resource information. The resource information contains the objects managed by federated services, which represent component resources.

The LIR and GRR are the repositories of local and global resource information derived from local health information providers and other providers, respectively. The GRR has a hierarchical mechanism, structurally similar to DNS, and each GRR has its own name. A service broker discovers resources, establishes their cost and capability, and then prepares a schedule to map requesting jobs to resources, as shown in Fig. 3. A job has a task specification that specified a list of operations to be performed [35]. To process a job, the broker dispatcher deploys its Agent on that resource. The agent performs a list of commands specified in the job's task specification. A typical task specification contains necessary commands and health records, including RFID tag information and locations of patients, from one of the agent resources, execution of the commands, and finally copying results back to the peer client. It also contains special commands for accessing records from the remote database. The broker looks at the replica catalog for a list of sites providing federated services, checks the status of those sites, and chooses a suitable site. The sites should be deployable in forms flexible enough to conform to the requirements of operations of various scopes and complexities; and provide valuable and reliable information. Furthermore, the technologies, shared data and terminology are standardized from a variety of agencies.

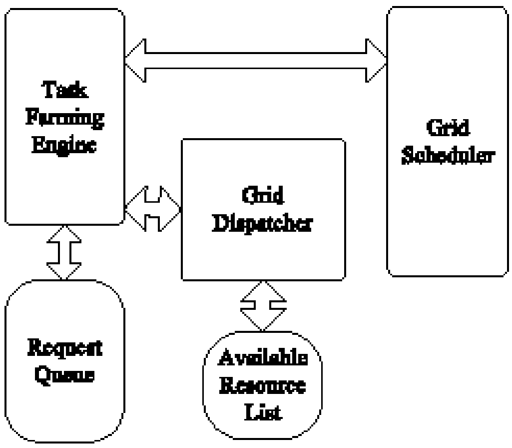

Fig. 3 Task scheduling of a service broker over a grid infrastructure.

The proposed architecture is built on a well-established JXTA platform, and is designed for Infectious Disaster Management. JXTA, an acronym of Juxtapose, initiated by Sun Microsystems, is a set of open and generalized peer-to-peer protocols that allows any connected device (cell phone to PDA, PC to server) on the network to communicate and collaborate. Almost every P2P application introduces a different protocol, replicating work already done and causing unnecessary incompatibility [36]. Since JXTA is a good and common protocol, it is adopted as our building block in the proposed system. The framework has to be built on a unified environment, to maximize the flexibility of the instantiation.

The brokers have to be flexible to exchange distributed messages within this health information federation at the current stage of development. The service brokers are designed as a JXTA based-architecture, and the implementation framework of the model is presented in Fig. 4. The interface and Implementation repositories supply meta-data for object instantiation by model factories. All brokers expose the corresponding interfaces to external service providers. Health Information Providers talk to middleware through commercially available platforms. Every piece of shared content managed by Content Management Service is referenced by a unique content identifier based on a 128-bit MD5 checksum generated from the content data. Additionally, every shared content item has an associated content advertisement that provides meta-information describing the content, including the content name, length, mime type, id and description.

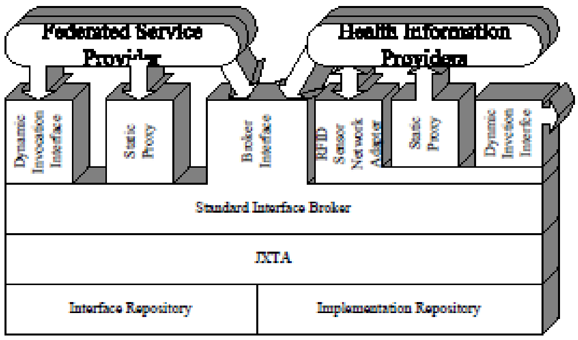

Fig. 4 The service broker implementation framework.

All our instantiated components are deployed over a software bus, called a DII (Dynamic Invocation Interface), as illustrated in Fig. 5. The implementation details of the components, including language, physical location, and interface specification, are hidden by the model factories. The objects are instantiated by corresponding model factories. Rather than linking the infrastructure by a predefined protocol, a set of protocol descriptions is stored on the interface repository, and each object instance only interacts through the interface factory to communicate with other object instances or applications.

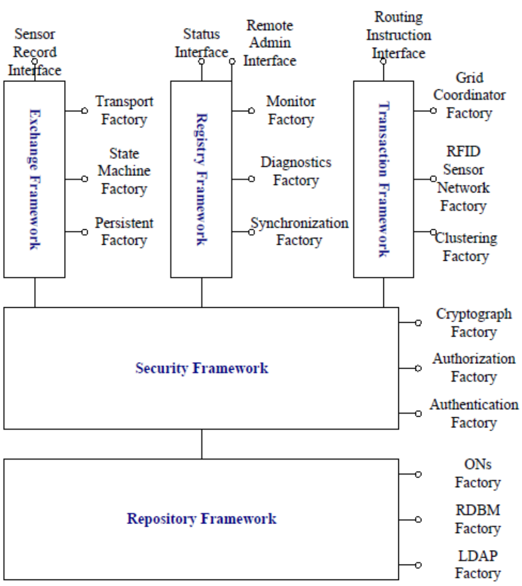

Fig. 5 Model factories framework over a DII (Dynamical Invocation Interfaces).

The DII comprises five sub-frameworks. Structured data are accessed via the Repository sub-framework. The Security sub-framework manages all authentication and authorization issues. The exchange sub-framework provides the flexibility of arbitrary choice of communication transport. Administration housekeeping is undertaken in the Registry sub-framework. The Transaction Framework is the major part of this architecture, and includes transaction commitments and rollbacks to meet the operation requirements of infectious disaster management applications.

4 Conclusion

The proposed national health information federation has many advantages, especially at the human level, for infectious disaster response. . The proposed implementation provide the following practical benefits: (1) it is user friendly, so that all infectious disaster responders have immediate access to the information that they need, when they need it; (2) it is incorporated by personnel into everyday tasks to ensure functional familiarity during infectious disasters; (3) it is cost-effective, and (4) it can be deployed inexpensively by hardware and software.

The health information federation system also provides several benefits at the application level, since it provides various services for information sharing and infectious disaster responsiveness. The federated GIS service allows the mapping of specific data sets to geographic coordinates. The federated architecture based on grid technologies jointly replicates a logical service at many points in a network. Accordingly, some or all of the associated data may also be replicated. Distributed applications, compared to centralized counterparts, offer agreeable trade-offs owing to proper replication. They are more likely to be available for service; have lower latency, no bottlenecks and no single points of failure or attack, and permit multiple routes to a service. However, grid architectures involve designs that are more complicated, may be temporarily inconsistent, and may be difficult to administer. The proposed architecture achieves a common understanding of spatial data and processes, yet also provides effective response to disasters. Grid federation offers responders to collect, process and distribute information rapidly, thus allowing informed planning and improved outcomes. The role of grid technology is likely to become increasingly important in public health surveillance and intervention. GIS and RFID wireless technologies provide a promising solution to many technical challenges in accelerating the responsiveness for infectious disaster management.

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