A Cross-Functional Service-Oriented Architecture to Support Real-Time Information Exchange in Emergency Medical Response

Logan Hauenstein, Tia Gao, Tsz Wo Sze, David Crawford, Alex Alm, and David White

Abstract— **Real-time information communication presents a persistent challenge to the emergency response community. During a medical emergency, various first response disciplines including Emergency Medical Service (EMS), Fire, and Police, and multiple health service facilities including hospitals, auxiliary care centers and public health departments using disparate information technology systems must coordinate their efforts by sharing real-time information. This paper describes a service-oriented architecture (SOA) that uses shared data models of emergency incidents to support the exchange of data between heterogeneous systems. This architecture is employed in the Advanced Health and Disaster Aid Network (AID-N) system, a testbed investigating information technologies to improve interoperation among multiple emergency response organizations in the Washington DC Metropolitan region. This architecture allows us to enable real-time data communication between three deployed systems: 1) a pre-hospital patient care reporting software system used on all ambulances in Arlington County, Virginia (MICHAELS), 2) a syndromic surveillance system used by public health departments in the Washington area (ESSENCE), and 3) a hazardous material reference software system (WISER) developed by the National Library Medicine. Additionally, we have extended our system to communicate with three new data sources: 1) wireless automated vital sign sensors worn by patients, 2) web portals for admitting hospitals, and 3) PDAs used by first responders at emergency scenes to input data (SIRP).**

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I. Introduction

Real-time information communication presents a persistent challenge to the emergency response community. First responder disciplines including EMS, Fire, and Police and health service facilities (hospitals, auxiliary care centers, public health departments), which typically function as individual units, must work together during mass casualty events. An effective response effort requires these teams to assess and adapt to the rapidly changing needs of the patients by sharing real-time information with often-limited resources over an unreliable communication infrastructure. Accurate and timely information exchange allows a critical sequence of interdependent events to occur. Patient information from the incident drives the proper allocation of resources such as ambulances and care facilities, while information on availability of care facilities and ambulances steers the management of patients at the scene.

EMS communities today depend upon hand-held radios and paper-based reports to communicate. These two methods of communication, however, are labor intensive and prone to human error. To facilitate the exchange of disaster information among the disparate teams over hand-held radios, the Department of Homeland Security and the Association of Public Safety Communications Offices (APCO) proposed interoperable communication standards for handheld radios. This proposed communication system is undoubtedly necessary. Radio communications, however, often exhibit usability and scalability problems during mass casualty emergencies. The failure of radio communications was demonstrated in the 9/11 attacks. As stated in the 9/11 Commission Report, "coordinating the units was rendered difficult, if not impossible, by internal communications breakdowns resulting from the limited capabilities of radios and confusion over which personnel was assigned to which frequency [1]."

II. System Overview

Recent advances in information technologies have made it considerably easier to share information between disparate systems – even in the chaotic environment of medical emergencies. Our service-oriented architecture addresses critical interoperability challenges through 1) the design of optimal data models to support a diverse variety of data from disparate systems, 2) the design of data exchange standards to access the data model, and 3) the design of web services that support the information needs for each system. Information is managed in coherent data models by the AID-N database server. Information is transmitted between systems through a set of publicly available and descriptive web services [2]. The AID-N web services operate on top of the widely-supported Simple Object Access Protocol (SOAP).

Our architecture allows us to interface with three deployed systems: 1) a pre-hospital patient care reporting software system used on all ambulances in Arlington County, Virginia (MICHAELS), 2) a syndromic surveillance system used by health departments in the Washington area (ESSENCE), and 3) a hazardous material reference software system (WISER) developed by the National Library of Medicine[3][4][5]. We also interface with three research systems: 1) a mesh network of wearable vitals-monitoring sensors for patients, 2) a web-based disaster information portal, and 3) a PDA used by first responders at disaster scenes to input patient-related data (SIRP) [6][7][8]. This accurate and timely information exchange has the potential to dramatically enhance effective collaboration among responders, increase the quality and quantity of patient care, and support the efficient delivery of patients to hospitals.

III. Server Architecture

The AID-N web services architecture is built upon a detailed database structure. The web services schema embodies the various concepts that comprise a disaster scenario, from higher-level elements such as incidents, treatment zones, and care facilities, down to low-level elements such as the triage status of patients and wind directions at the scene. The data ingested by the model are generally never deleted or replaced. Because of this, it is possible to "replay" the events that occur in a disaster scenario, providing a useful tool for disaster review and training.

Software systems that directly access a centralized database are difficult to maintain because: 1) minor changes in database structure can easily cause severe errors in the software clients, and 2) dealing with database drivers in different client platforms can complete software development. AID-N's web services address these problems by introducing a layer of abstraction around the shared database. This layer of abstraction provides a number of benefits to software developers who wish to share data using AID-N's data model:

- Removes database driver dependencies from client software
- Simplifies low-level database access details and complicated SQL queries
- Reduces required amount of database-specific error handling code
- Provides a higher-level object structure for the client software to use that is more attuned to their individual viewpoint
- Isolates database changes from the client software
- Increases flexibility of data security issues

Clients who wish to share data in an environment without a shared data model would normally be required to distribute their data to N different other clients who are interested in the data, requiring the data-producing client to implement N different interfaces in order to distribute the data to all interested parties in a peer-to-peer fashion. Errors that occur during data transmission could delay distribution to all of the other clients. This method of distribution is quickly becoming obsolete.

A core benefit afforded by AID-N's service-oriented architecture (SOA) is the simplification of data sharing. Data-producing clients need only write their data to a single place using a simple web service. Data-consuming clients can then call a web service to read the updated data from the shared data model. As a result, all of the clients who access the web services have a coherent and accurate model of the disaster response scenario.

Fig. 1 illustrates an overview of the types of information exchanged between systems that use the AID-N web services. The AID-N SOA collects patient triage information at a disaster scene from multiple sources, such as the wearable sensors or the Surveillance and Incident Reporting PDA (SIRP). This data, once converted into the shared data model, can be accessed by clients who are interested in the information. The same process takes place for all parties interested in dispersing or consuming data about the disaster.

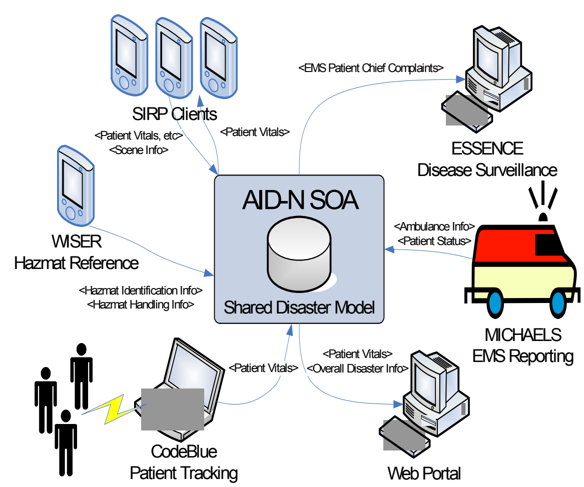

Fig. 1 Overview of the AID-N SOA and the types of data exchanged between the clients.

IV. Integrated Information Systems

A. Wearable sensors

Previously, we reported the development of wearable sensors for patient monitoring [9]. These sensors collect a diverse variety of patient information, including vital statistics, triage status, alert conditions, location, and state of contamination. Sensor data is continuously transmitted from the sensors to base stations over a wireless ad-hoc mesh network, known as Codeblue [10]. Base stations forward the data to the AID-N server. From there, the range of patient data can be accessed by interested clients.

B. SIRP

The Surveillance and Incident Reporting PDA (SIRP) is a handheld device on which paramedics can collect and report valuable patient and incident information. SIRP allows emergency responders to:

- Review patient information from vitals sensors (Fig. 2)
- Record additional information for patients such as chief complaint, apparent syndromes, gender, age, current location, and location at the time of the injury or onset of illness
- Capture images of the incident or patient
- Collect other disease information at the event, such as animal sicknesses, apparent environmental hazards, weather conditions, etc.
- Record and review incident information, such as hazardous materials and maps of marked areas of the disaster scene

By accessing data on the AID-N server, SIRP brings a wealth of important information to the fingertips of the emergency responder. By automatically transmitting recorded data to the AID-N server, SIRP allows efficient sharing of real-time information.

C. Web Portal

To illustrate the capabilities of our SOA, we developed a web-based information portal allowing different first responder disciplines to access the patient and disaster information in real-time. Using web services, the web portal application collects up-to-date aggregated data from the shared data model to present an accurate picture of the disaster situation. Three user groups for this web portal include:

- Emergency department personnel use the portal to retrieve information about the patients who are being transported to their hospital (Fig. 3).
- Incident commanders use the portal to see summaries of patients at particular disaster scenes. Since patients are tracked by sensors, the incident commanders can review the number of patients for each triage color and their location. This allows them to properly allocate available resources and make informed requests for additional resources.
- Medical specialists, often located at distant facilities, may be called upon to give treatment instructions to the medics at the scene. These specialists can use the portal to view real-time medical data of the patients being treated to identify those that require secondary triage.

D. MICHAELS

MICHAELS, a pre-hospital emergency incident reporting application developed by OPTIMUS Corporation, is currently used in Arlington County Virginia's ambulance fleets. MICHAELS transmits patient, disaster, and ambulance information to the AID-N web service architecture where it is made available to other systems such

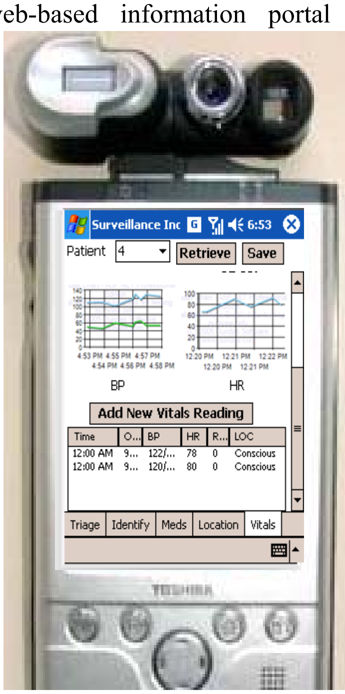

Fig. 2: SIRP displays systolic and diastolic blood pressure (BP) and heart rate (HR) from vital sign sensors readings.

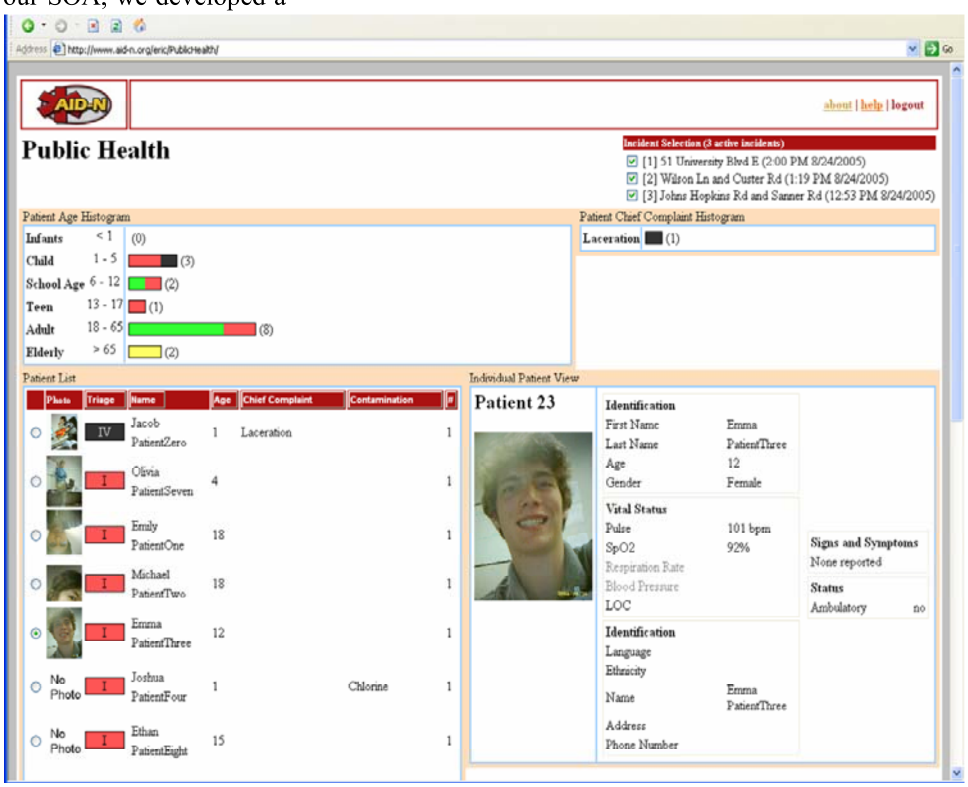

Fig. 3: The Public Health web portal shows histograms of patient age and chief complaint cohorts for currently active incidents. The "Patient List" shows triage details and patient photos captured through SIRP. The "Individual Patient View" shows detailed patient data collected from SIRP and vital sign sensors.

as ESSENCE and SIRP.

E. ESSENCE

The Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE) collects health indicator data from multiple sources to allow officials to search and analyze community health data. ESSENCE is used by epidemiologists at public health departments in the Washington DC metropolitan region. Using an AID-N web service, ESSENCE can consume the data produced by MICHAELS. Once processed, this data can provide health officials with a more complete informational overview of the disaster.

F. WISER

As a final example, we describe data integration with Wireless Information System for Emergency Responders (WISER) system. The WISER system helps first responders identify hazardous materials at a disaster scenario and provides instructions for how to treat and contain those materials. A first responder would use WISER to identify a hazardous material at a disaster scene. WISER shares this data with the AID-N web service architecture where the data can be distributed to the incoming responders and disaster managers in a context-specific way. For example, firefighters might receive instructions on how to appropriately put out the fire caused by the hazardous material while EMS staff might receive information on how to decontaminate patients exposed to the material.

V. CONCLUSION

The AID-N SOA provides a highly useful system to support information exchange between heterogeneous systems involved in a disaster response. The systems described earlier benefit greatly by sharing and consuming the data housed by the SOA. The SOA enables easy translation of data standards. Future development efforts will center on refining the shared model of the disaster scenario, adopting forthcoming data standards, and integrating security features into our applications.

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