SoSE Modeling and Simulation Approaches to Evaluate Security and Performance Limitations of a Next Generation National Healthcare Information Network (NHIN-2)

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Abstract – The emerging National Healthcare Information Network (NHIN) is intended to improve the efficacy, efficiency, and safety of healthcare. At the same time, Service Oriented Architectures (SOAs) are rapidly becoming an accepted means of providing network information exchange across a heterogeneous fabric of node, and may be suitable for a next-generation NHIN-2s. Given the complexity NHIN and SOA due to multiple levels of system interactions, creating a valid and usable SoSE model for SOA application using a single technique that captures the desired level of details can be a daunting task. In this paper we give details of a hybrid approach to modeling and simulation of a specific SOA that is named MCSOA and has been configured for potential defense applications. Further, we show how MCSOA could be used to link low-communications-capability healthcare data from sources like the Alaska Telemedicine Testbed Project (ATTP) to the proposed NHIN-2.

1 Introduction

In 2004, President Bush authorized the US Department of Health and Human Services (HHS) to initiate the design and development of a first generation National Healthcare Information Network [1,2]. NHIN by nature is a complex System of Systems Engineering (SoSE) challenge because contemporary healthcare depends on multiple disparate clinical specialists (e.g., radiologist, cardiologist, or rheumatologist) and care-delivery-providers (e.g., hospital, physician office, or home care), each using specialized computer systems for optimal clinical data and practice management. In addition, telemedicine tools are creating an ever-expanding diversity of points-of-care, creating a growing number of smaller healthcare subsystems that extend to personal, consumer-based health care technologies.

One aspect of emerging SoSE research relates to the emergent properties that complex systems exhibit, because those behaviors – and problems – are often quite distinct from those exhibited by the individual systems alone. In healthcare, for example, a primary goal of the NHIN is to create Electronic Health Records (EHRs) for all citizens by 2014. The elimination of disparate silos of computer- and paper-based patient records has been identified as a critical change needed to eliminate 30-40% wasted healthcare dollars caused by duplicated and erroneous processes, and tens of thousands of annual serious patient injuries and deaths believed caused by drug errors [3], [4].

In this paper, we will be using the Alaska Telemedicine Project to illustrate potential applications of a novel advanced Service Oriented Architecture (SOA), known as the Multi-Channel Service Oriented Architecture (MCSOA), to leverage and improve that system's security and performance in the context of the overall emerging US NHIN [5], [6], [7], [8].

2 The Alaska Telemedicine Project

The huge geographic area of Alaska, combined with the sparse pockets of population and ever-growing eco- and adventure-tourism presents many novel healthcare challenges For example, the Bristol Bay, Alaska region is roughly the same size as the state of

Pennsylvania (PA), but that region has a population of only 8,300, compared to over 12 million in PA. In the mid-1990's, the Bureau of Indian Affairs built and deployed a telemedicine system to enable improved remote wound and Ear-Nose-Throat (ENT) diagnosis and treatment from Anchorage. Between 1996 and 2001, this Alaska Telemedicine Testbed Project (ATTP) was used to treat thousands of patients. Several unique aspect of ATTP have been reported, including

- Statistically significant 50% reductions in antibiotics dispensed;
- Per-case costs were reduced by 50%;
- Near-equivalent patient satisfaction was found, which is notable when compared to lengthy, expensive, and delay-prone air-transport to Anchorage; and
- Successful use of narrow 900-1200 baud communication to send color still and moving images and text over Alaska's switched and satellite telecommunication infrastructure.

The healthcare situation is made more complex by the continued rapid growth of Alaska tourism, The Census Bureau's estimate of Alaska's population is 663,661, while in 2006 Alaska hosted over 1.6 million tourists, a number that grew by over 27% since 2001 [9,10]. Nearly 1 million of all tourists travel by cruise boat, but still, the number of tourists who travel by other means nearly exceeds the entire Alaska population. Fortunately, a significant number of cities near the cruise-ship routes south of Anchorage were part of the ATTP research. Similarly, most other tourists visit highly populated areas that were part of ATTP. Tourism is a major source of revenue for Alaska, bringing in over $1.6 billion annually for goods and services alone, and failure to provide adequate healthcare for those tourists could threaten that business.

It is fortuitous that the ATTP systems are in locations where they could possibly be leveraged for both local and visiting patients, but in order to successfully avoid complications like harming tourists by administering the wrong antibiotics that could cause injuries or death, for example, would require interfaces between the Alaska Telemedicine system and the emerging NHIN.

3 The US NHIN project

The NHIN project development process employs iterative, one-year analysis-design-prototype cycles. [11]. The design is coordinated by HHS using a teams of clinicians, providers, and researchers in what they call their American Healthcare Information Community (AHIC) [12]. AHIC specifies annual clinical and operational goals and requirements which are turned over to a more technology-focused team, known as the Healthcare Information Standards Panel (HITSP) [13], which identifies appropriate technical frameworks and standards to facilitate effective data interoperability among all providers.

The first year's NHIN design specifications were finalized in late October, 2006, were promptly reviewed and approved by AHIC, and then were formally accepted by the Secretary of Health in early 2007 [14]. During 2007 four teams of vendors and providers will build and test demonstration projects of what are know as Regional Healthcare Information Organizations (RHIOs), which are anticipated to be one core component of the US NHIN.

The anticipated RHIO architecture can be visualized as an open-ended number of proprietary, self-supporting regional star networks, which will have the job of facilitating relatively 'static' data transfers between local providers on a demand basis. This system will employ NHIN-compliant RHIO-to-RHIO gateways for regional/national data exchange. Each RHIOs may provide unique services, based on provider-customer demand, such as:

- transformation of providers' legacy data into NHIN-compatible formats,
- remote data repository and archiving services for providers, and/or
- managed patient-access to personal health data.

This paper addresses a number of the potential limitations of the NHIN's initial RHIO architecture, and explains how the robust and flexible MCSOA system being modeled, simulated, and developed for DoD's demanding defense applications could overcome those problems. Further, this paper discloses some preliminary MCSOA telecommunications simulation and modeling data to illustrate the way MSCOA could be use to successfully tie Alaska's Telemedicine project could successfully into the NHIN.

4 From SOA to MCSOA

Service Oriented Architectures (SOAs) are rapidly becoming an accepted means of providing network information exchange across a heterogeneous fabric of nodes. In terms of its architecture, a SOA is a system of systems (SoS) with complex interactions. On the other hand, SOA benefits include flexibility, interoperability, loose coupling and reusability. Owing to these advantages, the US Department of Defense (DoD) has defined a SOA framework for defense applications known as Net-Centric Enterprise Solutions for Interoperability (NESI) [15]. In this context, it is important to understand "defense" to also encompass natural disaster relief, homeland security, and other related national and global tasks because the diversity of those applications add remarkable complexity to the system requirements.

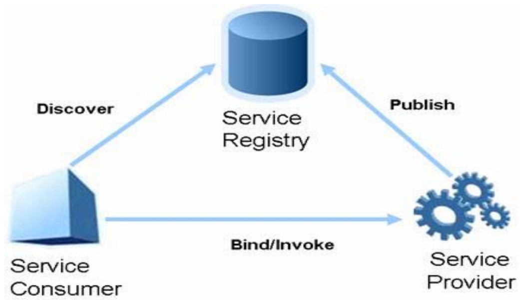

Figure 1. Traditional SOA model.

As shown in Figure 1, SOA traditionally is a distributed network architecture design approach that partitions service providers (or provision) from service consumers (or consumption), using service brokers to manage the process. Each self-contained Service Provider (SP) and Service Consumer (SC) communicates with each other when required using the Service Registry (SR) to handle the publishing and discovery of services. In SOA the SP and SC doe not depend on the state of other services, which creates a loosely coupled architecture that is easily reconfigurable. In the traditional SOA model, however, each SP, SC, and SR is presumed to be "always-on" and connected via durable and dependable communication links whenever a service is needed.

For example, in addition to the "typical" complexity associated with SOAs in other business contexts, understanding and incorporating the myriad of unique defense industry issues like huge data volumes, intermittent and widely-variant air and sea bandwidth challenges, scalability, diverse Communities of Interest (COI), life- and mission-critical data, and rugged security needs make accurate modeling, simulation, and design crucial to the successful design and implementation of SOAs for such applications.

In both the defense and healthcare contexts, a successful SOA must ensure robust and reliable operation in the most extreme environmental conditions (e.g., severe weather, power blackouts, erratic communication link lapses, natural disasters, etc.). Given the complexity of the a SOA that links tens of thousands of hospitals, physician offices, and clinics together with multiple levels of system interactions, creating a valid and usable SoS model for this SOA application can be a daunting task.

It is our belief, in fact, that using a single modeling or simulation technique cannot successfully capture adequate levels of how a SOA fabric handles data, transactions, or problems, which is why we have built modeling and simulation tools that simulate macro- and micro-level behavior of various SOA designs. At the macro-level, we are using the MESA library of SOA hardware system emulations created for DoD by Mitre. The MESA tools are integrated into a commercial discrete simulation software tool named Extend, allowing simulation of many different communication- or server-system limitations [7], [16], [17]. At the micro-level, we have used Colored Petri Net (CPN) tools to the precisely track and control the individual pathways and transformations used to handle each piece or packet of data [7], [18], [19].

As discussed in a different paper in this conference, the CPN and MESA/Extend tools are facilitating development of the robust MCSOA system for DoD [20], [21]. In this paper, those same DoD tools development, modeling, and simulation tools are described to illustrate the expected ATTP and NHIN-2 simulation, modeling, and design benefits. The authors recognize that other technical and/or commercial SOA tools might possibly be usable to achieve similar results, but the literature does not contain references to such resources.

5 NHIN-2 Linked to ATTP

As previously discussed, the RHIOs in the NHIN are static data-transfer and transformation services. Even if some or all of the RHIOs adopted traditional SOA designs, those would not likely meet the challenging requirements that stimulated MCSOA's development for DoD. Also, NHIN will have meet the regulations imposed by the federal Healthcare Information Portability and Accountability Act that took effect in the past several years [22], [23]. The HIPAA rules include obligations of Confidentiality, Integrity, and Availability (CIA)for all electronic data, not simply confidentiality, as commonly believed.

If a tourist from Boston became severely ill during an Alaska cruise, for example, in order for ATTP to function as part of NHIN-2, the system will have to successfully adapt to and overcome communication constraints. If the tourist had a prior surgery site that was now severely infected, photographs of the site might need to be sent to the Boston surgeon. In addition, known antibiotic allergy information may need to be sent from Boston to avoid dangerous side effects. Further, if a laboratory in a small Alaska town hospital does a culture of the infection and later discovers that the infection will be resistant to an alternate antibiotic being administered to the tourist, that information must be made available to caregivers immediately so that problem can be resolved promptly.

The CIA obligations under HIPAA relate to any electronic data used for the patient's care, regardless of local telecommunication constraints. As we will show, MCSOA enhancements can be made to handle this.

6 Enhancing MCSOA for NHIN-2

The following example uses our DoD MCSOA model, simulation, and data to show how we can create a HIPAA-compliant bridge between ATTP and the NHIN-2 system. This example shows how MCSOA facilities can make intelligent use of file compression algorithms to assure effective and reliable medical data, pictures or videos transfer between systems.

6.1 File compression, ATTP, and NHIN-2

In the ATTP, pictures and moving images are critical ways for remote care-givers and/or patients to show a distant physician how, for example, a wound is healing or what damage an ear infection is causing. As in some DoD air- and sea-based situations, data compression is essential for efficient communication the very narrow bandwidth available to remote Alaska sites. As a healthcare example, Mundy and Chadwick have observed that transmission efficiency of pharmacy prescription data can benefit significantly through use of compression [24].

There are a number of compression approaches that hold potential benefits for this domain, including BER, DER, PER, and XER, as described below.

ASN.1 (Abstract Syntax Notation One) is a high-level language for technology-independent encoding of message content. Since 1984 when it was formally defined [25], it has been used in telecommunications and computer networking for representing, encoding, transmitting, and decoding messages. ASN.1-based encoding methods include:

BER (Basic Encoding Rules) encodes data as (tag, length, value) triplets, with each component of the triplet specified by eight-bit octets. The "value" component can contain more than one additional triplet, enabling a tree-like data structure. BER's flexibility, however, allows for non-unique encodings which increase decoding complexity. **DER** (Distinguished Encoding Rules) is a canonical form of BER, which prescribes a single way for representing data, thus reducing decoding overhead.

PER (Packed Encoding Rules) is a more compact encoding than BER, where the number of bits used for data representation is minimized. PER approaches maximal compactness of data, while BER is only about 50% as efficient [26]. The superior compactness of PER requires the decoder to be given the abstract syntax of the data structure a priori, which may not always be practical. Compaction of bit data is unaligned and aligned on octet (byte) boundaries, with unaligned requiring fewer bits at the cost of added processing time due to non-uniformity.

XER (XML Encoding Rules) is a standardized set of rules for transforming ASN.1 data structures into XML, with BER commonly used as Binary XML [27], with BER providing better space efficiency that standard, compressed XML. Table 1 illustrates the significant benefit of BER over the popular zip compression for XML, on three levels of complexity of pharmacy prescriptions being transmitted.

Table 1. Comparison of BER and ZIP encoding.

Message Type	simple	semi-complex	complex
BER (bytes)	384	1,060	1,483
XML (bytes)	3,704	7,043	19,184
XML/BER	965%	664%	1294%
XML+zip (bytes)	913	1,737	4,733
XML+zip/BER	238%	164%	319%

Table 1 shows the several examples of the different sizes that different compression methods create from is simple, semi-complex, or complex source data.

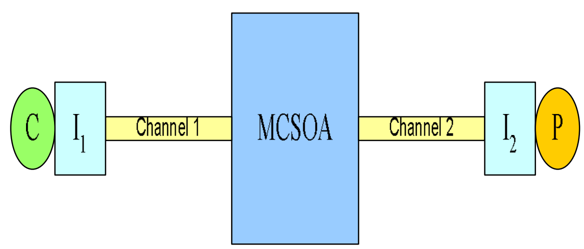

Figure 2. A MCSOA to facilitate data compression

A MESA/Extend or CPN simulation of a MCSOA node like that shown in Figure 2 can handle compression scenarios in which a message is compressed at interceptor *I1* and, after passing through the MCSOA node, is decompressed at interceptor *I2*. The total trip time can be computed by the formula

$$T_c = C_1(s, A_c) + k(1\text{-}r)s / b_1 + M((1\text{-}r)s) + k(1\text{-}r)s / b_2 + D_2((1\text{-}r)s, A_d)$$

where T_c is the total time needed to send the message with compression (sec),
s is the size of the message (bytes),
b_1, b_2 are the bandwidths of channels 1 and 2, respectively (bits per second),

$C_1(\,)$ is the compression time spent in I_1 running compression algorithm A_c including the interceptor overhead (sec),
r is the compression ratio (fraction of the size saved) of algorithm A_c,
$M(\,)$ is the MCSOA overhead for the compressed message (sec),
$D_2(\,)$ is the decompression time spent in I_2 running decompression algorithm A_d including the interceptor overhead, and
$k = 8$ is the bytes-to-bits transformation constant

In the Figure 2 MCSOA compression simulation, any form of compression, including no compression at all, can be applied at I_1 and I_2. Extensive experimentation has shown that, from a range of compression techniques including 7z, bzip2, gzip, Huffman, winrar, and winzip, that gzip performs consistently better that the other algorithms for all sizes of data, while winrar is competitive for very large data sizes. For the example of pharmacy prescription data, which is typical small in size, gzip outperforms the other algorithms by 2 to 44%. Although Huffman encoding is capable of achieving optimal-theoretic compression, in practice the other techniques to rely on more flexible encoding strategies produce better compression.

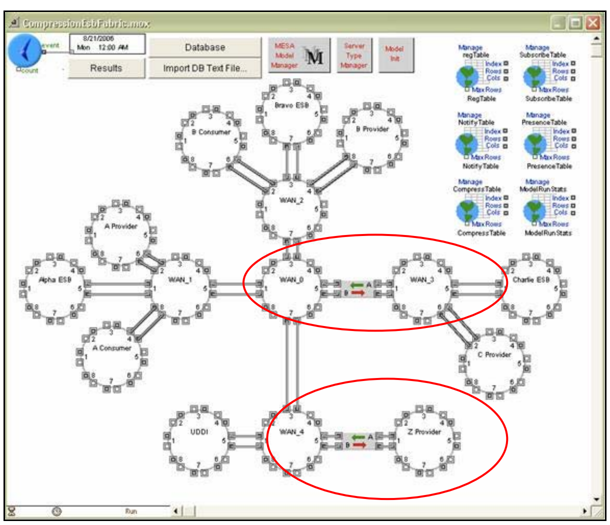

Figure 3. MESA/Extend MCSOA model with compression node

An example of a MCSOA MESA/Extend model is shown in Figure 3, and two pairs of potential enhanced-compression nodes are shown. By creating an appropriate quantity of enhanced-compression nodes that include matched compression and decompression software, improved MCSOA performance can be obtained. Furthermore, if one or more intelligent compression tools were implemented within the MCSOA system, they could automatically determine the best available compression algorithm to be used based on data characteristics. The MCSOA nodes could even include emergent considerations such as available bandwidth, network load and communications reliability.

7. CONCLUSIONS

In this paper, we have described the way modeling and simulation tools that are being developed for rigorous DoD deployment of SOA can be adapted to healthcare. We have focused on devising and enhanced-SOA-based system that could serve as a template for a next-generation NHIN-2. Such a system would allow connecting slow-speed remote telemedicine tools like those devised in Alaska without violating the HIPAA Confidentiality, Security, and Availability requirements.

Providing high levels of quality of service within the severely bandwidth limited domain described in the ATTP (900-1200 baud) is critical. Using modeling tools such as CPN and MESA/Extend can help characterize the behavior of various network architecture configurations under challenging ranges of operating conditions. These modeling and simulation tools can provide an invaluable predictive assessment of the feasibility of various approaches and can identify potential weaknesses. These approaches can help ensure that development of NHIN continues to meet its goal of saving lives, time, and money. By using DoD investments for related tasks, the public also gains a useful "dual use" and "peacetime dividend" of military investments.

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