Performance Analysis of a Medical Record Exchanges Model

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***Abstract*—Electronic medical record exchange among hospitals can provide more information for physician diagnosis and reduce costs from duplicate examinations. In this paper, we proposed and implemented a medical record exchange model. According to our study, exchange interface servers (EISs) are designed for hospitals to manage the information communication through the intra and interhospital networks linked with a medical records database. An index service center can be given responsibility for managing the EIS and publishing the addresses and public keys. The prototype system has been implemented to generate, parse, and transfer the health level seven query messages. Moreover, the system can encrypt and decrypt a message using the public-key encryption algorithm. The queuing theory is applied to evaluate the performance of our proposed model. We estimated the service time for each queue of the CPU, database, and network, and measured the response time and possible bottlenecks of the model. The capacity of the model is estimated to process the medical records of about 4000 patients/h in the 1-MB network backbone environments, which comprises about the 4% of the total outpatients in Taiwan.**

***Index Terms*—Electronic medical records, encryption, health level seven (HL7), queuing analysis.**

I. Introduction

THE rapid growth of information and communication technology has sped up innovation of clinical information systems. More and more patient records, laboratory reports, pharmacy drugs, and financial and health insurance data are now transferred through computer networks [1]–[4]. The benefits of medical record exchange (MRE), to name a few, include offering more information for physician diagnosis, providing better continuous care for discharged patients, and eliminating the waste of duplicated examinations.

About 23 million people live on Taiwan Island and almost all (98.67%) have joined the National Health Insurance (NHI) [5]. More than 17 000 health care organizations, including about 550 hospitals along with medical clinics, dentist clinics, nursing homes, and long-term care units are part of the system. The average utilization rate of the NHI outpatient service is about 14.8 visits/person/year. Total number of outpatients is about 296 million person-times/year. The largest hospitals have about 10 000 outpatients/day. In January 2004, the Bureau of National Health Insurance issued the IC-chipped health insurance card that is being used nationwide. One of its benefits is providing a convenient medical information exchange platform [5].

Numerous projects and field studies related to MRE have been conducted. The Department of Health in Taiwan has budgeted for the next-generation information network and the network health services projects [6]–[8]. Some projects have proposed the use of centralized server, but the large amount of medical data storage and transmission done is not feasible. We proposed a distributed medical record interchange model in which exchange interface servers (EISs) are installed in each hospital to take charge of the intra- and interhospital EISs communications through networking. A medical record index service center (MRISC) is responsible for the management, location of medical records, and the EIS address. To evaluate system performance, we applied the queuing theory to model the MRE architecture.

II. Literature Review

Currently, most hospitals have established their own electronic medical record systems. However, these systems only support individual hospitals and do not provide communication or share resources among hospitals. Therefore, it is difficult for a patient to visit his doctor in one hospital and have his medical record from another hospital available [9]. The long-term care units also cannot obtain discharge information from the hospitals [10]. Each healthcare provider must expend much time and effort to collect patient information, thereby causing data redundancy, and perhaps even jeopardizing patient health.

Numerous electronic data interchange (EDI) applications function in different areas, such as financial exchanges in banks and electronic databases found in libraries, but few applications are present in the Taiwan's healthcare system. The primary reason is that most hospital information systems (HIS) do not follow a common standard and they strive to protect patients' privacy, even though the demand for a patient record exchange has been extensive.

Health level seven (HL7) has been defined as a standard for EDI in the health care field for several years. Several reports address medical information exchange issues. Hutchison *et al.* proposed the HL7 reference model to integrate clinical and laboratory information and to solve the complex EDI problem [11]. Considerable achievement has been made using the HL7 interface in the US and Europe. Williams from Columbia University presented an HL7 message generator for a clinical information system that may save time in the system development [12]. Hu *et al.* and Xu integrated the database of medical applications

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platform in HL7 [13], [14]. In Europe, Heitman *et al.* used the HL7 clinical document architecture (CDA) as standardization communication in the national context of discharge and referral letters between the hospital information system and physician office system in Germany [15]. Goossen *et al.* in the Netherlands are developing a set of national domain information models to support electronic information exchange and electronic patient records using the HL7 V3 reference information model (RIM) as its methodology and tools [16]. Rassinoux *et al.* implemented the electronic patient record using the eXtensible Markup Language (XML) as a format of exchange messages in Geneva University Hospital, Switzerland [17]. The HL7 Taiwan organization was founded in 2001, and it has defined some standards in patient referral and observation reports, communicable disease reports, and health insurance claims [18].

Chapter 11 of the HL7 document defines the patient referral messages [19]. Using REF-I12 to send the patient examination, diagnosis data, and reply in the form of an RRI-I12 message has been proposed to HL7 Taiwan as a standard by the National Taiwan University Hospital. In addition to the REF/RRI-I12, the query message of RQC/RCI-I05 is helpful for the patient record exchange. According to HL7 Standard, an HL7 message is the basic unit of data transfer between the two systems. The REF-I12 message sends specific patient information from one hospital to another. The RRI-I12 is the return message of the REF-I12. RQC-I05 is a query message to request medical information for a specific patient. The RCI-I05 is the response message of the RQC-I05. The principal contents of the message are the patient ID, patient name, date of birth, address and phone numbers, health provider information, observations, and diagnosis data. They are encoded in a pre-defined sequence with distinct delimiters to separate segment fields and components.

The medical record is exchanged through the network with safeguards to ensure data security for protecting patient privacy. In Taiwan, the health certificate authorization (HCA) has been proposed for several years and it began issuing the certificates, in June 2003. One of the major functions of the HCA is to safeguard the exchanged medical records.

The open systems interconnection (OSI) security architecture X800 defines security services in the five categories of authentication, access control, data confidentiality, data integrity, and nonrepudiation [20]. The authentication service assures the communicating entity to be the one that it is claimed to be. The access control service prevents the unauthorized use of the resource. Data confidentiality protects data from unauthorized disclosure while data integrity assures that data received are exactly as sent. Lastly, the nonrepudiation measure prevents either sender or receiver from denying the transmitted message.

For access control, besides checking the user ID and password, one may verify the patient and physician's identification with the insurance IC card and the doctor's digital certificate. Other security services may employ the public-key cryptography. The public-key algorithm uses a pair of keys that is preselected, one key for encryption and the other key for decryption. Each user generates a pair of keys, one placed in a public register or other accessible file and the other kept private. The sender encrypts a message with the recipient's public key for confidentiality. Then, the sender signs a message with his private key for authentication and nonrepudiation.

The most widely implemented public-key algorithm is RSA. The RSA algorithm was invented in 1978 by Ron Rivest, Adi Shamir, and Leonard Adleman [20], [21]. The schema is

$$C = M^e \bmod n \tag{1}$$

$$\begin{aligned} M &= C^d \bmod n = (M^e)^d \bmod n \\ &= M^{ed} \bmod n \end{aligned} \tag{2}$$

where M is plaintext and C is the cipher text. The public key is $\{e, n\}$ and the private key is $\{d, n\}$. Each user generates a public/private key pair using the modular arithmetic in conjunction with the square and multiply algorithm [20].

Queuing models are useful for estimating the system response time and performance. According to Gross and Harris, "A queuing system can be described as customers arriving for service, waiting for service if it is not immediate, and if having waited for service, leaving the system after being served" [22]. This definition can be used to model the MRE system especially for the large amount of requests.

Kendall introduced a notation to characterize queuing models [23], [24]. It is a three-part code $a/b/c$. The first letter specifies the inter arrival time distribution and the second letter represents the service time distribution. For example, the letter G is used for a general distribution, M for the exponential distribution, and D for deterministic times. The third letter specifies the number of servers. The most widely used model is the $M/M/1$, where we have exponential interarrival time. Applying the basic queuing theory, the electronic medical record (EMR) requests arrive at the system at a rate of λ requests per millisecond, queue for service, get served at a rate of μ requests per millisecond, and depart. The EMR requests stay in an average response time [25], [26]

$$R = \frac{\rho/\lambda}{1-\rho} = \frac{1/\mu}{1-\rho} = \frac{1}{\mu-\lambda} \tag{3}$$

where the ratio of request arrival rate and the system service rate

$$\rho = \frac{\lambda}{\mu} \tag{4}$$

is the utilization of the system.

III. Methods

To model the systems in the queuing theory, the arrival rate of the request, and the service rate of the CPU, database, and network are estimated. We simulate the environment of querying a patient record. When the system is possibly busy with a service, the simulation sets process queues during waiting. We estimate the process time spent at each process queue. Then we apply the queuing theory to calculate the system response time and to compare the system performance to identify bottlenecks in the system. Most of the simulation programs and functions in the models have been implemented in this study. We evaluate the system capacity and response time, and discuss the system performance.

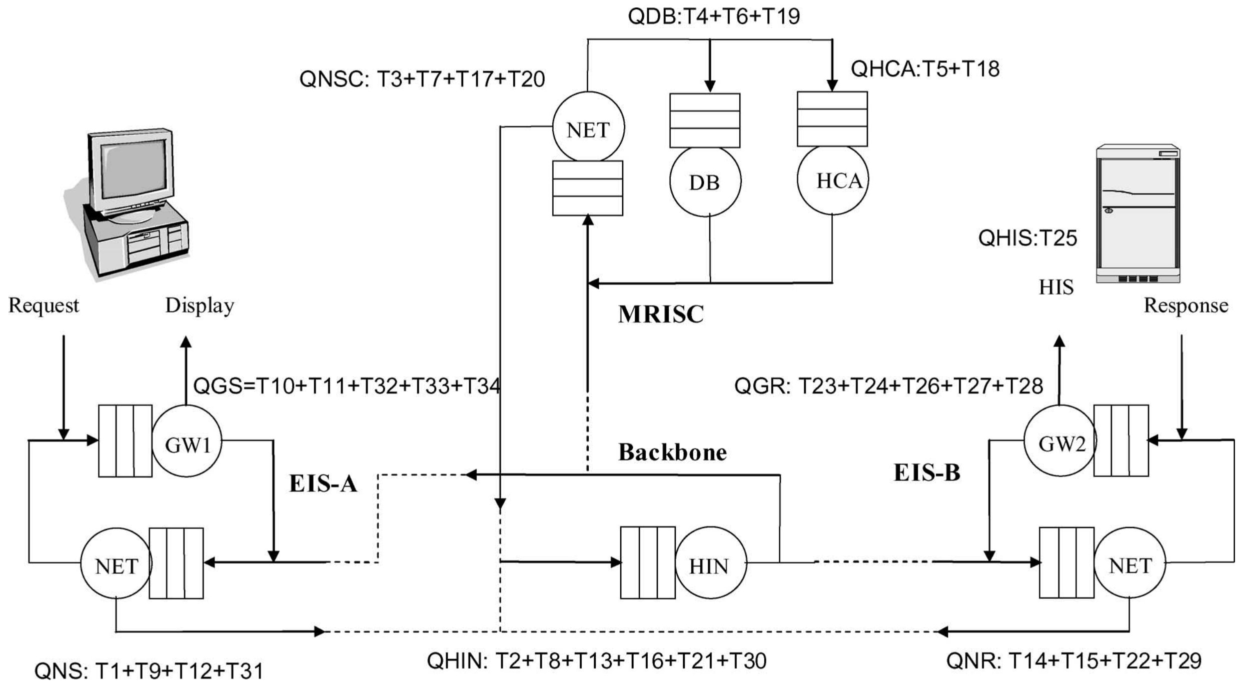

Fig. 1. MRE queuing model. There are nine service queues. The total service time of each queue is the summation of time in each individual step. T_i corresponds to the service time for step i in Table II.

A. System Architecture

In a distributed MRE model, patient information is stored in different hospitals. Suppose the patient insurance IC card records the visited hospitals from which one can trace the medical records. EIS servers are designed for each participating hospital to cooperate with a MRISC. The EISs are responsible for communications between the information systems inside a hospital and other EISs in the extranet. The MRISC is responsible for the management of the EISs address, public key, and the MRE logs.

The following is the hypothesis scenario for requesting a patient record from hospital A to hospital B in Fig. 1.

- A patient hands in his insurance IC card and his doctor inserts his certificate card into a card reader in a client computer at hospital A.
- The client computer sends a request to the EIS_A for the patient records in another hospital.
- The EIS_A queries the address and public key of the EIS_B from the service center MRISC.
- The EIS_A encodes an HL7 query message RQC-I05. The patient ID and name are put into the PID segment and the hospital ID is contained in the PRD segment.
- The EIS_A encrypts the message (or digest) with the private key of the EIS_A and the public key of the EIS_B.
- The EIS_A sends the message from hospital A to the EIS_B at hospital B.
- The EIS_B decrypts message with the private key of the EIS_B.
- The EIS_B requests the public key of EIS_A and decrypts the message into plain text (or digest).

TABLE I
QUEUE ABBREVIATION AND DESCRIPTION

Abbreviation	Description	Type	Step of service in TABLE II
QHIS	Queue of querying the EMR from HIS	Database	25
QGS	Queue of the request gateway	CPU	10, 11, 32, 33, 34
QNS	Queue of the request network	Network	1, 9 , 12, 31
QNSC	Queue of the service center network	Network	3, 7, 17, 20
QDB	Queue of the database in MRISC	Database	4, 6, 19
QHCA	Queue of the HCA	Database	5, 18
QNR	Queue of the response network	Network	14, 15, 22, 29
QGR	Queue of the response gateway	CPU	23, 24, 26, 27, 28
QHIN	Queue of the HIN(100kb Internet)	Network	2, 8, 13, 16, 21, 30

- The EIS_B parses the HL7 message RQC-I05.
- The EIS_B queries the patient record from the information system at hospital B.
- The EIS_B encodes an HL7 response message RCI-I05.
- The EIS_B encrypts the message (or digest) with the private key of the EIS_B and the public key of the EIS_A.
- The EIS_B sends the message back to the hospital EIS_A.
- The EIS_A decrypts the message with the private key of the EIS_A and the public key of the EIS_B.
- The EIS_A parses the HL7 message RCI-I05.
- The EIS_A responds by sending the patient record to the client computer.

We simulate the process of making a request for a patients' medical record to eventually receiving the result in 34 steps. Nine queues are required in the patient record interchange environment. The abbreviation and description of each queue are listed in Table I.

- QGS: The QGS is a CPU queue on the request side for generating and encrypting HL7 messages RQC-I05 as well as decrypting and parsing RCI-I05 messages.
- QNS: The QNS is a network queue of the LAN on the request side for sending and receiving the RQC/RCI-I05 messages as well as querying the destination address and public key from the MRISC.
- QHIN: The QHIN is the network queue of the health information network backbone. All the messages send from one LAN to another wait to pass through the HIN.
- QNSC: The QNSC is the network queue of the MRISC that provides services for querying EISs addresses and public keys.
- QDB: The QDB is a database queue for awaiting the service of querying the destination address from the MRISC.
- QHCA: The QHCA is a database queue for awaiting the public key service from the HCA.
- QNR: The QNR is a network queue of the LAN on the response side for receiving RQC-I05 messages and sending RCI-I05 message returns as well as for the querying traffic of the public key from MRISC.
- QGR: The CPU queue of the EIS server on the response side. The QGR provides the service for generating and encrypting RCI-I05 messages as well as decrypting and parsing RQC-CI05 messages.
- QHIS: A database queue awaiting the service for querying medical records from the hospital information system.

Then, we monitor and record the procedure between sending a request and receiving the result. The procedure consists of nine queues and 34 steps. In Table II, we list the relation of each step and queue in the MRE cycle.

B. Assumptions and Estimations

We assume that the arrival time of an outpatient at a hospital and the EMR request is a Poisson distribution. Some common modules for MRISC and EIS have been implemented, and it is assumed that each hospital can develop the query programs to extract an EMR from HIS. To protect the patients' privacy, messages with any patient information must be encrypted in the receiver's public key and signed in through the sender's private key.

To model the system response time, we need to estimate the rate of the request λ and the service time $1/\mu$ of each queue. We divide these nine queues into three types in Table I. One is the CPU type, including QGS and QGR; the second one is the database type, including QDB, QHCA, and QHIS; the third one is the network type, including QNS, QNR, QNSC, and QHIN.

We estimate the service time of the CPU type by developing an HL7 encoding/decoding and encryption/decryption program and executing 1000 loops to calculate the average time. The system takes about 12 ms to generate an HL7 message and about 50 ms to parse the message. For message encryption and decryption, service time dependent on the size of message, the system takes about 300 and 680 ms for processing RQC-I05 and RCI-I05, respectively.

TABLE II
SEQUENCE OF THE MRE MODEL

Step	Event	Queue	Service Time (millisecond)
1	Query address and key (send)	QNS	5.4
2	HIN network backbone	QHIN	565
3	Query address and key (receive)	QNSC	5.4
4	Query gateway address (DB)	QDB	83.3
5	Query key (HCA)	QHCA	400
6	Insert GW1 log to DB	QDB	2
7	Reply address and key (send)	QNSC	5.4
8	HIN network backbone	QHIN	565
9	Reply address and key (receive)	QNS	5.4
10	Generate HL7 message RQC-I05	QGS	12
11	Encryption RQC-I05	QGS	300
12	Send RQC-I05	QNS	5.4
13	HIN network backbone	QHIN	565
14	Receive RQC-I05	QNR	5.4
15	Query public key (send)	QNR	5.4
16	HIN network backbone	QHIN	565
17	Query public key (receive)	QNSC	5.4
18	Query public key (HCA)	QHCA	400
19	Insert GW2 log to DB	QDB	2
20	Reply public key (send)	QNSC	5.4
21	HIN network backbone	QHIN	565
22	Reply public key (Receive)	QNR	5.4
23	Decryption RQC-I05	QGR	300
24	Parse message RQC-I05	QGR	50
25	Query EMR database	QHIS	6888
26	Generate message RCI-I05	QGR	12
27	Encryption RCI-I05	QGR	680
28	Insert log to GW2	QGR	2
29	Response message RCI-I05 (Send)	QNR	5.4
30	HIN network backbone	QHIN	565
31	Response Message (Receive)	QNS	5.4
32	Decryption RCI-I05	QGS	680
33	Parse message RCI-I05	QGS	50
34	Insert log to GW1	QGS	2
35	Display		

For the database queues, we created a database table, about 100 B in 10 fields for each record. We measured the response time of querying a record from different tables with different number of records. The results are presented in Table III. The service time of querying the database is dependent on the total number of records in a table. It increases about 2 s for each 100 K records at the first query. For the second and subsequent queries, the response time is similar as the first one for large size data, but less than one-tenth the time for small size data. For example, if the total number of records is 1000 K, both the first and the second queries take 18 s. However, if the total number of records is 500 K, the first query takes 10 s and the second query requires only 1 s. Loading data from a disk

TABLE III
RESPONSE TIME OF QUERYING FROM DIFFERENT NUMBER OF RECORDS IN A DATABASE TABLE

Number of records (thousands)	The first time query	The second time query (seconds)	Query two records (seconds)	Query three records (seconds)
23	1	0	0	0(1/12 each)
230	6	0	1	1(2/5 each)
500	10	1	1	2(3/5 each)
760	14	1	2	3
1000	18	18	35	52
1500	27	27	53	79

consumes mechanical time that is much longer than the IC processing time in the computer memory. The small size data may be loaded from a disk and saved in the computer memory during the first query. During the second query, it is not necessary to re-load the data. Theoretically, the response time of a query database is in complexity of a binary search of $O(\log_2 N)$. To simplify the model, we assume that the databases are well indexed and the indexes are resident in the memory. For a large number of records N, we assume the response time of query as $\log_2(N/760\ 000)$. The number of 760 000 is our measured number of records in 1 s of query.

We obtained a list of hospitals and imported 17 K records into our database. We were able to execute 12 queries/s. The service time is about 83 ms for each query. If HCA is to issue 200 K certificates, then the service time is estimated to be about 400 ms (see Table III). If the total number of records of EMR database in a hospital have about

$$3(\text{records/outpatient}) \times 3 \times 10^6(\text{outpatient/year}) \times 10(\text{years}) = 9 \times 10^7 \text{ records} \quad (5)$$

the service time is estimated to be

$$\log 2(9 \times 10^7/760\ 000) = 6.888 \text{ s}. \quad (6)$$

To insert a log into a database is very fast. We can append about 500 records/s. The service time for inserting a log is only 2 ms.

It is difficult to estimate the network service time for transmitting medical records. We applied the data of Heidemann *et al.* [27]. According to their findings, the minimum theoretical time of sending a 5-kB webpage through the Ethernet is about 5.4 ms, through the 100-kb Internet is about 565 ms, and through the 1-Mb Internet is about 129 ms. Here, the 1-Mb Internet is a computer network having a bandwidth larger than 1.02 Mb/s.

To estimate the number of requests, we use the number of outpatients in hospitals. According to the report, total number of outpatients is about 296 million people-times in year 2001, in Taiwan. Most of the hospitals do not offer outpatient services on Sunday. We estimate about 947 404 patient visits/day. If the patient visits are distributed across 10 h from morning to evening, the average number of outpatients recorded is 100 000/h. If $1/25$ or 4000, of the patients requires querying medical records from other hospitals per hour, we can calculate the arrival rate $\lambda_T = 4000/3600/1000/\text{ms}$ for the MRISC. In a large hospital, about 10 000 outpatients or 1% of total patients per day exists. If the number of the requests and responses are equal for the hospital, then we can assume the arrival rate $\lambda_S = \lambda_R = \lambda_T/100$ for the EIS, and estimate the response time.

IV. RESULTS

The service rate μ and arrival rate λ can be applied to (3) for calculating response time R. For example, the service rate of 100-kb Internet QHIN is

$$\mu = 1/(T2 + T8 + T13 + T16 + T21 + T30) = 1/(565 \text{ ms} \times 6) = 0.295/\text{s}. \quad (7)$$

If 100 medical records are exchanged during each hour, the arrival rate λ_T is $100/3600$ or about 0.028/s. The response time is

$$R_{\text{QHIN}} = 1/(\mu - \lambda) = 1/(0.295 - 0.028) = 3.74 \text{ s}. \quad (8)$$

If the exchanges are increased to 1000/h, λ_T is about 0.28/s, and the response time becomes 58.1 s. Another example in the QHIS, the service rate μ is 1/6888 ms or 0.145/s. The arrival rate in a hospital λ_R is only 1% of λ_T in MRISC. If a total amount of 100 medical records are exchanged, the arrival rate λ_R is 100/3600/100 or about 0.00028/s and the response time is

$$R_{\text{QHIS}} = 1/(\mu - \lambda) = 1/(0.145 - 0.00028) = 6.9 \text{ s}. \quad (9)$$

If the exchanges are increased to 1000/h, λ_R is about 0.0028/s and the response time is still kept at about 7.02 s.

Using similar rules, we may estimate the response time in different request rate for each queue. The results of the MRE model are calculated using MS-Excel and are shown in Table IV. When the numbers of exchanges are increased from 100 to 4000, we found the response–time increase is less than 30 ms in the queue of QNSC, QDB, QNS, QNR, QGS, and QGR. It means that the bottleneck is unlikely to be in these queues. We select queues of QHCA, QHIS, and QHIN in both 100-kb and 1-Mb Internets and plot the response time curves in Fig. 2.

According to Table IV and Fig. 2, the system takes about 11 s for the 1-Mb Internet requests and 14 s for the 100-kb Internet on 100 requests. Most of the response time is spent on querying the HIS database (about 7 s). If the number of requests increases continuously to 1000 requests, the response time of the 100-kb Internet builds up quickly to 68 s, while the 1-Mb Internet still gives a good response time of about 11.2 s. Actually, Fig. 2 and Table IV show that the capacity of the 1-Mb Internet may support about 4000 patients' record exchanges per hour. The bottleneck of the 100-kb Internet arises from the bandwidth of the HIN while that of the 1-Mb Internet is the public key query of the HCA.

TABLE IV
RESPONSE TIME FOR EACH QUEUE

Number of medical records exchange (per hour)	100	500	700	800	900	950	1,000	2,000	3,000	4,000	4,300	4,450
QNSC	22	22	22	22	22	22	22	22	22	22	22	22
QHCA	818	900	947	973	1,000	1,014	**1,029**	**1,440**	**2,400**	**7,200**	**17,994**	**71,991**
QDB	88	88	89	89	89	89	90	92	94	97	98	98
QNS	22	22	22	22	22	22	22	22	22	22	22	22
QNR	22	22	22	22	22	22	22	22	22	22	22	22
QGS	1,045	1,047	1,048	1,049	1,049	1,050	1,050	1,056	1,062	1,069	1,071	1,072
QGR	1,045	1,047	1,048	1,049	1,049	1,050	1,050	1,056	1,062	1,069	1,071	1,072
QHIS	6,901	6,954	6,981	6,995	7,008	7,015	7,022	7,162	7,307	7,459	7,505	7,529
QHIN(100Kb)	3,742	6,406	9,947	13,742	22,226	32,157	58,118					
Total(100Kb)	**13,703**	**16,508**	**20,126**	**23,961**	**32,488**	**42,441**	**68,423**					
QHIN(1Mb)	791	867	911	935	960	973	986	1,358	2,180	5,529	10,250	17,895
Total(1Mb)	**10,752**	10,969	11,090	11,154	11,221	11,256	11,291	12,229	14,172	22,487	38,053	99,722

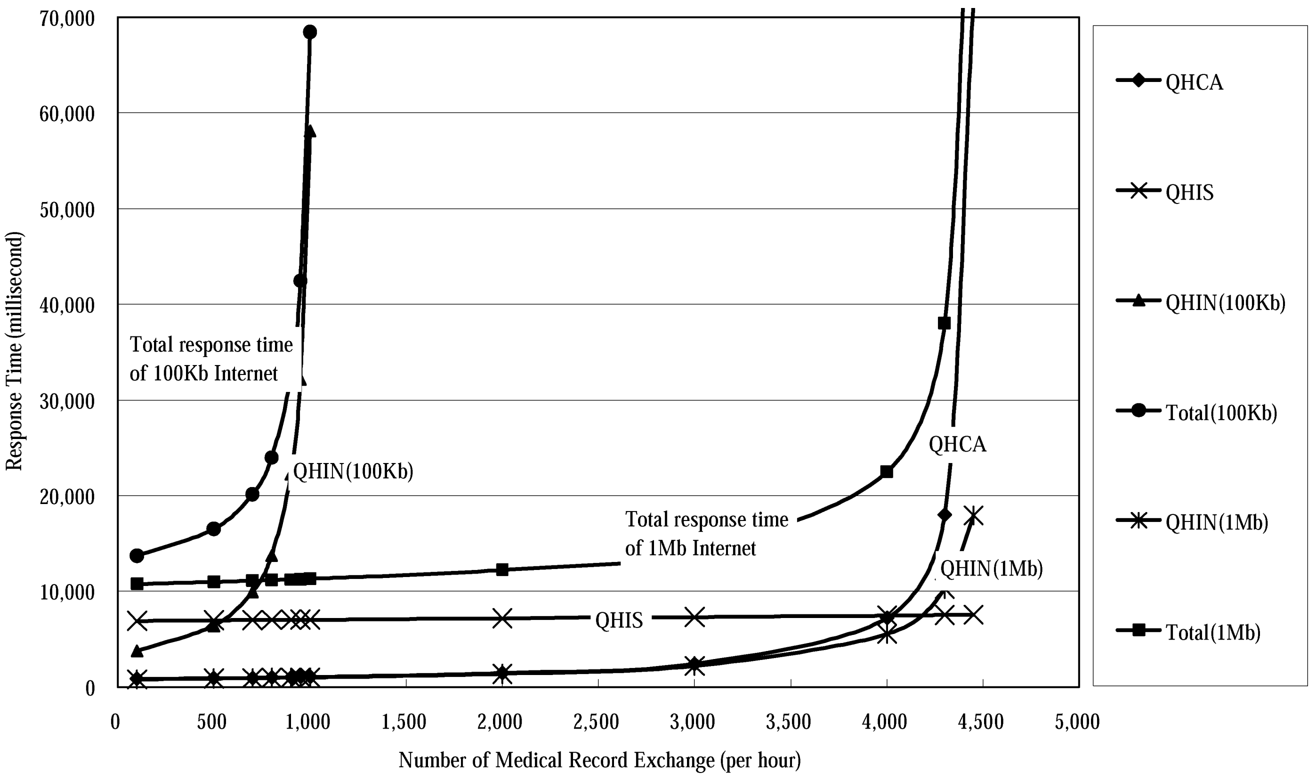

Fig. 2. Response time of MREs. The response time of QHCA, QHIS, and QHIN both in 100-kb and 1-Mb Internet are shown. The capacity of the model can process the medical records of about 1000 patients (see QHIN-100 kB) per hour in the 100-kb Internet and 4000 patients (see QHCA) per hour in the 1-Mb Internet environments.

V. DISCUSSION

We have developed a model to evaluate the capacity and bottleneck of MREs. From the model, we found that bottlenecks are in the network backbone or the database of the service center. All the exchange traffics have to pass the network backbone, but the bandwidth of the network backbone is smaller than LAN. Therefore, a bottleneck is most probable to occur in the network backbone. If the bandwidth of the network is expanded to a large enough size, another bottleneck could occur in the database queue of a service center. The public key is queried twice at each medical-record exchange. Because the arrival rate of MRISC (λ_T) is much larger (100 times) than that of EIS in each hospital (λ_S and λ_R), the bottleneck only occurs in the queues of MRIST but not in EIS. The response time of QHIS is always kept about the same (see QHIS) in each hospital and will not be a bottleneck. We suggest that expanding the bandwidth of the network backbone and the equipment capacity of MRISC will decrease the workload and improve the system performance.

Our study does have some limitations. The information systems differ for each hospital. We did not implement the EMR query from the HIS; there only an estimate the service time of the database queue is given. Compared to the amount of the requests in MRISC, the amount of EMR requests in each hospital is small. The response time of the EMR query in each hospital can be treated as a constant. We assumed that the patient arrival rate is evenly distributed across the 10 h daily, but did not take into account the busy hours in some exceptional occasions. We did not investigate the number of MREs among hospitals and only assumed that the requirement is less than 4% of outpatients. A more accurate value requirement can be further investigated in the future. We used a personal computer with a 1.6-GHz CPU and 256-MB RAM in the Widows-2000 and SQL-database environment, a conservative model. With improved computing facilities in modern hospitals, better performance for MRE can be anticipated. In the models, the time unit of measurement is seconds, but the service time in the theoretical calculation approaches milliseconds in the model. If one employs better measurement tools for time performance evaluation, then the relevant data in this study could be more accurate.

The memory space of the health insurance card is 32 kB. It is impossible to save the entire medical record onto an IC card, but it is possible to save just the hospital ID that a person visits. A hospital ID code could be compressed to a 2 B binary code for only about 17 000 hospitals in Taiwan. Most people visit less than 20 hospitals throughout their lifetime. A 40-B memory space is relatively small when compared with the total 32-kB memory space in the IC card,

Each citizen in Taiwan has a unique ID number. The ID number is applicable to both the National Health Insurance IC card and the medical record system in each hospital. As found in other countries, the master person index linking [28] to maintain consistency across the medical record system is unnecessary. To simplify the prototype system, only the hospital ID (where), the range of patient visit dates (when), and the ICD-9 CM code (what) can be incorporated into the ID number (who) as query keys that can be easily converted into the structure query language (SQL) of a database. ICD9-CM codes exist in all hospital medical records, because they are used for NHI insurance claims. Concept mapping is also an important issue for advance query and medical records exchanged among heterogeneous databases [29]. It requires a system like the unified medical language system (UMLS) [30] to maintain sophisticated medical terminologies as well as semantics. It should be considered for implementation in the future.

In this study, we did not measure the service time of multimedia data exchange such as X-ray films, CT, or MRI scans, etc. If medical images are requested, we hypothesize the bottleneck will occur in the Internet backbone not in the CPU. Image processing and DICOM format transformation only occur in the local EIS or workstation. If we apply the minimum theoretical time of 2800 ms for sending a large-cluster multimedia data in the 1-Mb Internet [27], the model may support only about 200 multimedia patient record exchanges each hour. If one wants to improve the multimedia data communication performance, the bandwidth of network backbone should be extended.

Information and communication technology are progressing rapidly. Several factors, such as the development of the high-speed Internet backbone of the National Health Information Infrastructure (NHII), the gigabit local area network, the higher CPU speed, and the larger RAM size in the computer servers, will affect the performance of an MRE model. The model may also promote development of other medical applications such as telemedicine in which the physician and homecare patient can exchange medical data via Internet.

VI. Conclusion

To summarize, we have implemented a prototype system to simulate the MRE model. The functions of this system include the HL7 message generation, parsing encryption, decryption, and format transformation. The system accepts user input data from a patient ID, destination hospital, and the duration of the medical records to generate an RQC-I05 query message. After encryption in RSA algorithm, the message is sent to the destination in HTTP protocol. When receiving the query message, the system decrypts and parses the message and constructs a database SQL command. Then, the system generates an RCI-I05 message with an EMR encryption and response.

An exchange interface server is established in each hospital to examine message encoding, decoding, encryption, decryption, and communication with other servers. A service center allows for the query of server addresses, public key, and the management of exchanges. The distributed model uses the health insurance IC card to record of visited hospitals while using minimum computer and network resources in the transmission of EMR.

We applied the queuing theory to the model system, simulated the response time, and identified bottlenecks. Upon examination of the data exchange capacity of the model, we found the system can process the medical record for about 1000 patients/h in the 100-kb Internet and 4000 patients/hour in the 1-Mb Internet environments. These numbers represent about the 4% of the total outpatients on Taiwan.

Due to the limitations of our study environment, some subsystems, like authentication by the HCA and query medical records from HIS, have not been implemented yet. In the near future, our objectives are to develop a standard interface for enhancing the efficiency of the health information exchange in various hospitals information systems. Our long-term goal is to study advanced information technologies in the health and medical application area that will benefit more patients.

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