Ubiquitous Data Accessing Method in IoT-Based Information System for Emergency Medical Services

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***Abstract*—The rapid development of Internet of things (IoT) technology makes it possible for connecting various smart objects together through the Internet and providing more data interoperability methods for application purpose. Recent research shows more potential applications of IoT in information intensive industrial sectors such as healthcare services. However, the diversity of the objects in IoT causes the heterogeneity problem of the data format in IoT platform. Meanwhile, the use of IoT technology in applications has spurred the increase of real-time data, which makes the information storage and accessing more difficult and challenging. In this research, first a semantic data model is proposed to store and interpret IoT data. Then a resource-based data accessing method (UDA-IoT) is designed to acquire and process IoT data ubiquitously to improve the accessibility to IoT data resources. Finally, we present an IoT-based system for emergency medical services to demonstrate how to collect, integrate, and interoperate IoT data flexibly in order to provide support to emergency medical services. The result shows that the resource-based IoT data accessing method is effective in a distributed heterogeneous data environment for supporting data accessing timely and ubiquitously in a cloud and mobile computing platform.**

***Index Terms*—Decision support system (DSS), emergencymedical service, Internet of things (IoT), resource model, ubiquitous data accessing.**

I. Introduction

ADVANCEMENTS in Internet of things (IoT) technologies present enormous potential for the high-quality and more convenient healthcare servicing. By employing these technologies in the activities of healthcare servicing, doctors (managers in medical centers) are able to access different kinds of data resources online quickly and easily, helping to make emergency medical decisions, and reducing costs in the process. In China, due to the increasing needs of huge population, the different systems between rural and urban health care, the accessibility and availability of medical data, etc., a lack of sufficient information sharing is one of the most basic challenges in healthcare servicing.

Much effort has been made in China to solve the problem of clinic data sharing among hospitals. In Shanghai, integrated clinic information platform has been explored to exchange data among hospital information systems. Resident health document systems have been built in some districts for residents to store and access their electronic medical records in cloud computing environment [1]. These efforts improve the clinic data environment for medical researchers to obtain more patient data conveniently, but it is not enough to support diagnosing, especially in emergency medical services, when more data need to be accessed quickly across organizations to coordinate group activities. Health Level 7 (HL7) provides the application-level standard for clinic data exchanging of network protocol [2]; however, it is still difficult for practicing purpose.

In the last decade, a growing number of researches have been conducted toward using IoT technology to acquire data ubiquitously, process data timely, and distribute data wirelessly in the healthcare field [3], [4]. In [5], Ambient Assisted Living (AAL) is designed to support daily activities of elderly people independently as long as possible. In [6], IoT technology is used to support medical consultations among rural patients, health workers, and urban city specialists. With the use of IoT, M-health concept, which is defined as mobile computing, medical sensors, and communication technologies for healthcare, attracts more and more researchers applying fourth-generation (4G) mobile communication technology and IoT in healthcare service [7].

The above-mentioned uses of IoT technology bring both opportunity and challenges in ubiquitous data accessing medical services. More attentions have been paid in developing ubiquitous data accessing solutions to acquire and process data in decentralized data sources [8]–[10]. In [11], the software adaptation approaches are surveyed in ubiquitous computing for resource-constrained devices to react to the changes of user requirements actively and transparently. In [12], control functionalities are designed to coordinate hybrid wireless networks in cloud computing. In [13], a metro system based on data-centric middleware is simulated to publish/subscribe message remotely. In [14], researchers use publish/subscribe-based middleware to disseminate sensor data in cyber-physical systems. A cloud platform is developed in [15] to handle heterogeneous physiological signal data to provide personalized healthcare services. In the related research, clinical data heterogeneity is still the main obstacle that hinders the clinic data integration and interoperation.

Recently, RESTful (Representational State Transfer) resource-oriented model has been extended from a kind of software architecture originated from Web service research mainly for

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Web service interoperation to Web resources management. Using RESTful, Web services could be retrieved by URI (Uniform Resource Identifier) addresses [16]–[19]. It is can be flexible for resource representation [20], and for ubiquitous service application with wireless communication [21]. In this research, we propose a ubiquitous data accessing method (UDA-IoT) to deal with the heterogeneity of IoT-based data in medical service using RESTful architecture and show that using IoT technology successfully in the healthcare area is beneficial to both doctors and managers.

The rest parts of the paper are organized as follows. In Section II, the UDA-IoT method is proposed and discussed on how to tackle the problems of accessing distributed heterogeneous IoT data across organizations ubiquitously. In Section III, the details of how to implement the UDA-IoT method are discussed. In Section IV, a case study of implementing UDA-IoT in emergency medical service is introduced. Finally, Section V concludes the paper.

II. Data Model for IoT-Based Medical Services

A. Activities and Roles in Medical Services

Healthcare service is a dynamic process that mainly includes pretreatment processing, in-treatment processing, and post-treatment processing, as shown in Fig. 1.

In Fig. 1, healthcare servicing activities include not only within hospitals but also out of hospitals such as medicine and equipment supplying and insurance document processing. Diverse departments and different kinds of patients, professional staff, physicians, and doctors are involved in the entire healthcare serving process. Doctors need to access patient data to know medicine-taking history, and these kinds of data can be stored in a distributed manner. It may also be needed to access data from the equipment to know busy/free working status and the location to obtain data.

Nowadays, IoT technology is used widely in the healthcare service process [22]. For instance, medicines are bar-code labeled so that they can be delivered more correctly to patients and ambulances/equipments are global position system (GPS) and radio frequency identification (RFID) connected so that they can be located more quickly. Therefore, it becomes both an important and a challenging issue for doctors and managers in medical centers to share medical information during medical service processing, because it is such a process requiring close cooperation. Different objects are connected by IoT notes together to deliver healthcare activities to patients. These IoT notes must adapt to connect to IoT. Take a common Chinese hospital in Shanghai as an example, ambulances use GPS sensors to connect to IoT, patients and physicians use their ID cards to be identified, bar codes are used for medicines to be scanned to the hospital information systems, and valuable medical apparatus and instruments use RFID tags to be located.

In order to assist doctors and managers accessing data resources efficiently, a data model that is semantic and flexible is needed to support heterogeneous data sharing, especially in the big data environment in IoT application. The semantic data model is expected to be self-explaining, supporting diverse and distributed data storage, as well as flexible and efficient data sharing. Furthermore, for healthcare service, it is important that data can be accessed anytime and anyplace conveniently.

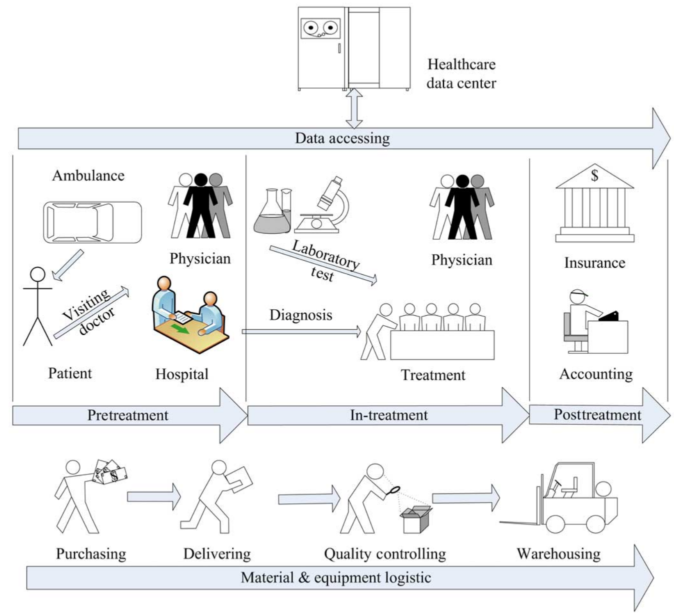

Fig. 1. Activities in healthcare servicing.

B. Meta Data Model for Ubiquitous IoT Data Accessing

Summarizing the features of the medical services, we conclude that the ubiquitous data accessing for IoT data (UDA-IoT) in medical service needs to have the following functions:

1) to support accessing data in heterogeneous formats;
2) to be useful in building real-time application system;
3) to be able to access big data.

In order to meet the above-mentioned requirements, we present a unified metadata model to describe IoT notes, in which data are heterogeneous in format, to facilitate data sharing and data interoperating, as shown in Fig. 2.

In Fig. 2, the data structure consists of three layers, including *value, annotation, and semantic explanation*. *Value* refers to the range of data to reflect the fact in healthcare servicing or the attribute of the patients. *Annotation* refers to the caption of the data for retrieval. *Semantic explanation* refers to the common definition of the data for data-sharing purpose.

In the metadata model of Fig. 2, compared with traditional data structures, such as relational data structures, our data model emphasizes the self-explanation of data value for accessing data ubiquitously, rather than the definition of data structures for data organization. Each IoT data is notated and defined in XML format, so that it is self-described and can be accessed from Web. Because each item of data is defined with ontology, it could be explained in semantic level and shared with other instances of similar or related concepts.

Another advantage of our data model is that it is more flexible for big data application. In the application of IoT, data volume is huge and increases rapidly. In order to meet the requirements of big data in IoT, the definition of data relationship, which is the data structure definition in traditional data model, is included in the ontology, so that it can be more efficient in data storage using NOSQL databases.

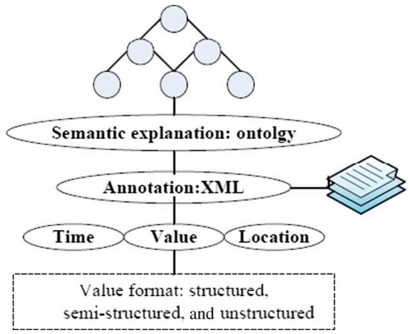

Fig. 2. Metadata model for IoT note.

For IoT application in medical servicing, each IoT note is added by the information of time tag and location tag. The time tag is valuable for real-time application system. The location tag would be significant in smart medical services for active positioning of the valuable medical apparatus and instruments.

III. The UDA-IoT Ubiquitous Data Accessing for Information System in Medical Services

A. Mapping Between IoT Physical Entity and Information Entity

In the application systems based on IoT, physical entities are connected to the information systems through sensors or tags, which become the representations of physical entities in information systems. The information systems cannot transfer physical entities directly; instead, the representations of the physical entities are transferred to realize the interactions of the physical entities. For example, in case someone wants to know if the medical ward of room #3203 in the hospital is occupied, he/she could access the status of the representation of the physical entity of "*medical ward room #3203*" in information systems. Formally, we define this kind of information representation as entity-oriented resource (EoR).

EoR is the mirror image of physical objects in information systems, including all attributes of the physical object, but not including the functions that can be performed by the entities. For example, EoR "*Sprinter-324 Ambulance*" defines the attributes of *displacement, speed per hour, stretcher, oxygen tank, breathing machine, medical monitor*, etc., but not defines the functional features, such as *start-up, march forward*, and *turn round*, which will be defined in transitive resource in Section III-B. To summarize, EoRs are the representation of the nonfunctional attributes of the physical entities.

The definition of EoR is as follows.

Definition 1: EoR:

$$\begin{aligned}\mathrm{EoR} := \langle URI, AttrSet := \langle Attributes\rangle, Persistence\\ := \langle Driver, Address, Authentication\rangle\rangle\end{aligned}$$

URI is the unique address for the application systems to access the physical entities, in which the EoR corresponding to the representation of the physical entity is actually stored. *AttrSet* is the attribute set of the EoR. *Persistence* declares to the data storage layer the location, sources, and the accessing of the content of the EoR. It needs to be emphasized that an EoR is corresponding to unique URI, but the content of the EoR can correspond to more than one *persistence.* In applications, once the EoR is defined, its URI is exposed to the application layer. In contrast, *persistence* is transparent to the application layer.

In IoT application, some physical entities are composed of other physical entities; for instance, EoR of "*Sprinter-324 Ambulance*" composed of other EoRs, such as *stretcher*, *breathing machine*, and*medical monitor*. The representation of the composed physical entities in the information systems are defined as *compositedEoR* (cEoR). cEoRs are dynamic. They can be combined or decomposed according to the requirement of the business. For example, "*Sprinter-324 Ambulance*" can be decomposed to excluding *breathing machine* and *medical monitor*, taking only *stretcher* and *oxygen tank*. In detail, entity composition can be fulfilled in two ways: 1) reference; and 2) aggregation. Entities composed by aggregation can be decomposed or recomposed according to the business requirements, whereas entities composed through reference cannot be decomposed. For instance, cEoR of "*Sprinter-324 Ambulance*" is related to the physical entity of "*driver*" by reference, which cannot be decomposed from the ambulance.

The definition of the cEoR is as follows.

Definition 2: cEoR:

$$\begin{aligned}\mathrm{cEoR} &:= \langle URI, Composition\\ &:= \langle EoR/cEoR, Type\ \mathrm{reference/\ aggregation}\rangle \mathrm{AttrSet}\\ &:= \langle attributes\rangle\rangle\end{aligned}$$

Composition means the other entity resources composed in the composited resources. The way of compositing, *reference*, or *aggregation* are defined explicitly. It is important to point out that the composed resources might be normal entity resources or composited entity resources. In order to explain the concept of EoRs and cEoRs clearly, entity relationships are depicted in Fig. 3 using an application example.

In Fig. 3, cEoR "*Sprinter-324 Ambulance*" is composed of *breathing machine,stretcher, oxygen tank*, and *medical monitor* by *aggregation*, meanwhile composed of nurses by *reference*. Resource of "*Nurse"* is composed of ID card by *reference*. When the IoT application systems call for the physical entity of "*/Ambulance/S324*", the entire representation of the "*Sprinter-324 Ambulance*" in the information system, including *breathing machine,stretcher, oxygen tank, medical monitor*, and the *nurses* in the ambulance, is accessed. If some equipments of the ambulance are out of work, the entity resource can be adjusted by recomposition or decomposition. For instance, when the status of the breathing machine of "*./ER/x-117*" in the ambulance of "*./Ambulance/S324*" displays that it is out of work, the resource of "*Sprinter-324 Ambulance*" can be recomposited to aggregate breathing machine "*./ER/x-102*" from "*./Room/3309*" instead of breathing machine "*./ER/x-117*".

Using EoR and cEoR provides a flexible method for mapping a physical entity to an information entity in the IoT applications. Entity resource model is a kind of referred model in which there is only one copy of the entity resource data for one physical entity. When the state of the physical entity is changed, the transition is triggered to copy the resource model so as to keep the similarity

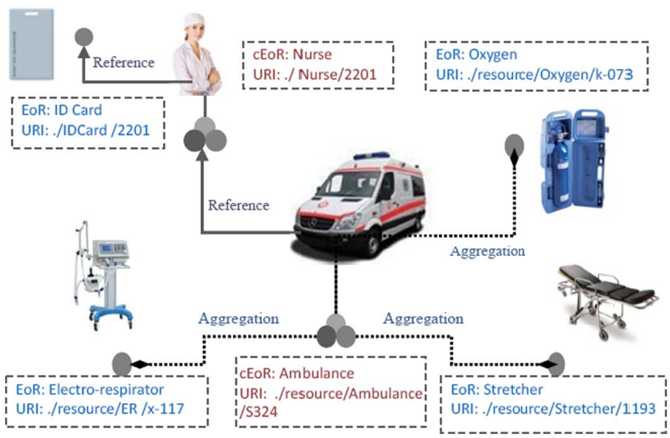

Fig. 3. EoR and cEoR.

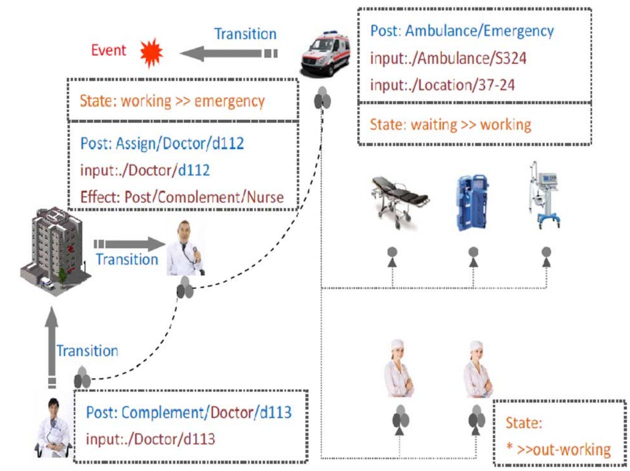

Fig. 4. Example of transitive resource.

of the physical entity with its representation. As the transition only takes place within the copy of the referred resource model, it does not require to propagate among multiple information systems. It can be efficient to keep the synchronization of the physical entity with its information representation and guarantee the timeliness of information flow.

B. Mapping Between the Business Function and Transitive Resource

EoR and *cEoR* models can perfectly describe the attributes of IoT physical entities in information environment, but the functional features of the IoT physical entities are unable to be described in the entity resource models, which are critical and essential to IoT applications, such as "*assigning ambulances-approaching to accidental location*," "*dispatching doctors to the ambulances*," and "*starting the rescuing pre-plan*". These functions of the physical entities are information services, responding to sets of operation unions on information entities. For instance, "*assigning ambulance approaching to rescuing location*" is one information service in which the URI of the used ambulance and accident location are needed to be transferred. As shown in Fig. 4, because that the ambulance is a kind of cEoR, when an ambulance is used, according to the definition of the cEoR of the *ambulance*, the related resource of the *ambulance*, such as the *driver, doctor, nurse, breathing machine, stretcher, oxygen tank*, and *medical monitor*, will be activated simultaneously. In other words, information services correspond to status transition of the entity resources. For instance, for information service of "*assigning ambulance*," the status of the *driver* changes from "*waiting*" to "*working*," the status of *doctor* changes from "*working*" to "*out-working*." In summary, the business functions are defined as transition-oriented resources (ToRs), which are denoted as follows.

Definition 3: ToR:

$$ToR := \langle URI, Input := \langle EoRs/cEoRs\rangle, Output := \langle EoRs/cEoRs\rangle, Pre\text{-}condition, Effect := \langle ToRs\rangle\rangle.$$

URI is the accessing address of the ToR. A ToR servicing can be started by *POST* method through *HTTP* protocol. A ToR being executed can be cancelled by *DELETE* method. *Input* refers to the entity resources activated by the transition resource. *Output* refers to the generated entity resources after the transitive resource servicing is executed. *Precondition* refers to the preconditions needed to start the transition resource servicing, such as the demanded status of the physical entities. *Effect* refers to the follow-up resource servicing, for instance, if one doctor leaves the job, other doctor needs to take the place.

C. Cloud Platform and Data Accessing Process with UDA-IoT

With the application of IoT and electronic medicine records technology in medical servicing, a large amount of healthcare data is accumulated. To deal with the big healthcare data, cloud platform with multitenant data management is used in our research, instead of traditional data distribution architecture, which is shown in Fig. 5.

In Fig. 5, the data management architecture is divided into three layers. The lowest layer is tenant database layer, which stores multitenant databases. The middle layer is data accessing control layer. We use resource control mechanism to organize distributed healthcare data in the middle layer. The top layer is business layer. It controls business activities and workflow to coordinate data sharing and data interoperation. The more details of the three data management layers are as follows.

Multitenant layer for cloud applications is the layer that connects to physics databases. There are two core components, which are shared databases and isolated databases. In big data applications, data are from multiusers. Similar to that in the healthcare applications, a patient's data may be distributed to completely different hospital databases, because one patient might go to different hospitals to see different doctors. Databases in different hospitals in the cloud platform should be isolated because of the organization information policy and patient privacy. Meanwhile, during healthcare servicing, with increasing demands of sharing data conveniently and efficiently, shared databases are designed to store common data definition for data accessing.

Resource layer is the key component for data accessing control in heterogeneous data application environment. The required data might be stored in different tenant databases and in different formats. In resource layer, data are declared as resources, so that

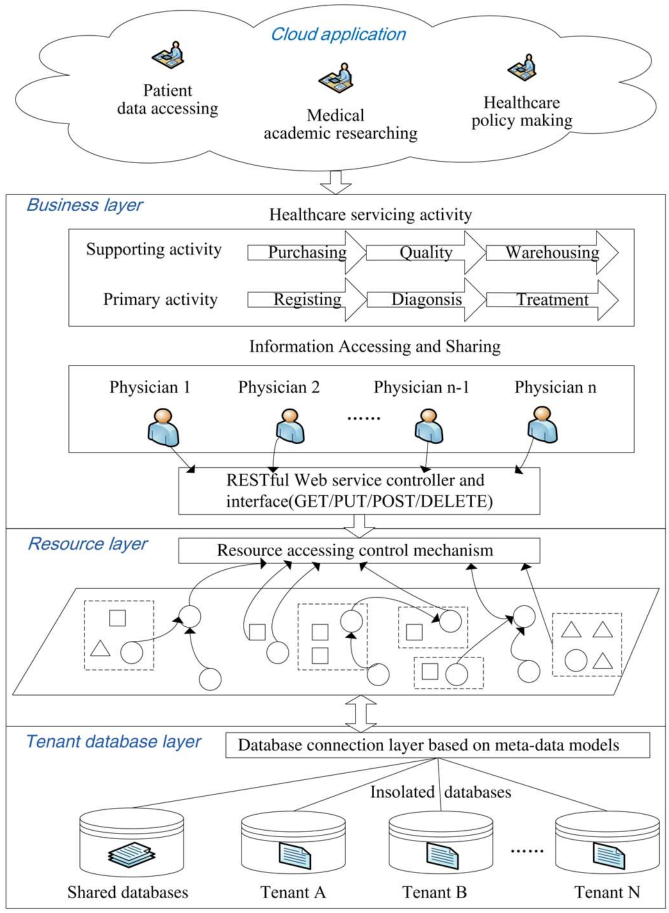

Fig. 5. Cloud platform for multi-tenant data storage.

the resource control mechanism is capable of facilitating, retrieving, and accessing. Resource accessing control mechanism interprets user's request of data accessing and convert that to tasks of resource retrieving from multitenants.

Business layer explains the logic of business activities and controls the data accessing. It sends the request of data accessing through interface by RESTful Web services to the resource management layer.

The process of ubiquitous IoT data accessing can be designed as follows.

1) Cloud application sends the data accessing requests.
2) Business layer checks the accessing right and sends the request to RESTful Web service if the request is approved.
3) The resource control mechanism facilitates the resource accessing request to be sent to database location and the database processing the request.
4) Database connecting layer fetch data from shared and isolated databases.

In the ubiquitous IoT data accessing process, IoT data is organized as data resources. They can be stored in any database with the unique URI of resources for ubiquitous accessing.

IV. Case Study

A. Emergency Medical DSS

Emergency medical services, such as in accident rescue, is a decision-making process that requires close cooperation, because usually more than one ambulances can be scheduled and assigned to send the injured people to more than one nearby hospitals. Taking the accident rescuing as an instance, in emergency medical services, actions need to be taken as quickly as possible. Mostly, decision makers have little time to discuss or getting feedback. More often, actions need adjusting to the changing events during decision implementation. Therefore, in emergency medical systems, it is crucial for decision makers to organize available resources quickly and to communicate with involved actors timely.

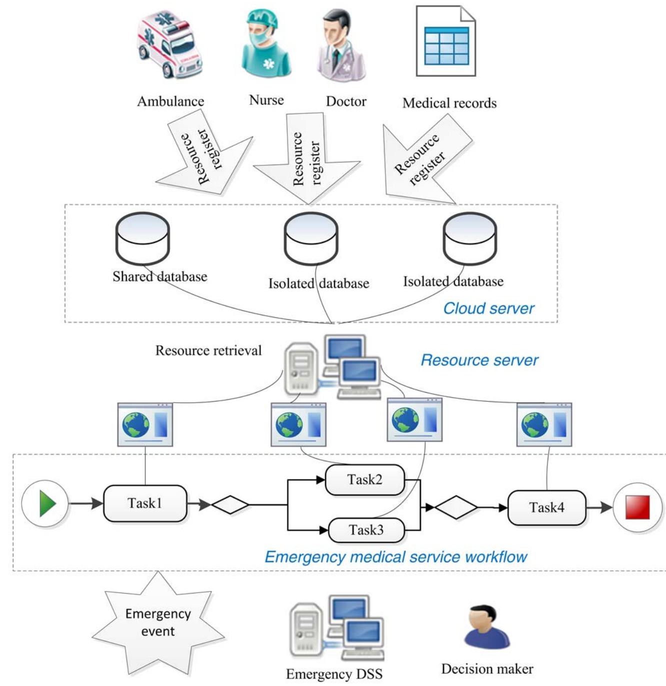

Fig. 6. Scenario of using UDA-IoT in emergency medical DSS.

Fig. 6 shows a scenario of using UDA-IoT to support emergency medical services. *Entity Resources and Data Resources*, such as ambulances, nurses, doctors, and medical records of patients are stored in the cloud server. When an EE occurs, medical service workflow is loaded, involving multiple tasks. Resources are required to execute these rescuing tasks.

As emergency events have the features of information uncertainty, emergency decision support systems (DSSs) are expected to be configured dynamically depending on the development of the events and the status of the resources to be used. In our research, we implemented a descriptive decision process to solve the emergency decision-making problems, as shown in Fig. 7. Our solution focuses on the decision implementation phase, emphasizing on the coordination and information sharing among task groups, instead of evaluating and choosing the alternatives, to facilitate information communication through ubiquitous data accessing.

In Fig. 7, the denotations are defined as follows.

Definition 4: Emergency Event $\mathrm{EE} = (\mathrm{Time}, \mathrm{Location}, \mathrm{Object}, \mathrm{Target})$*:* EE denotes emergency event, which is defined in terms of time and location of the event that took place, objects the event affected, and the target as what the decision-making is expected to achieve.

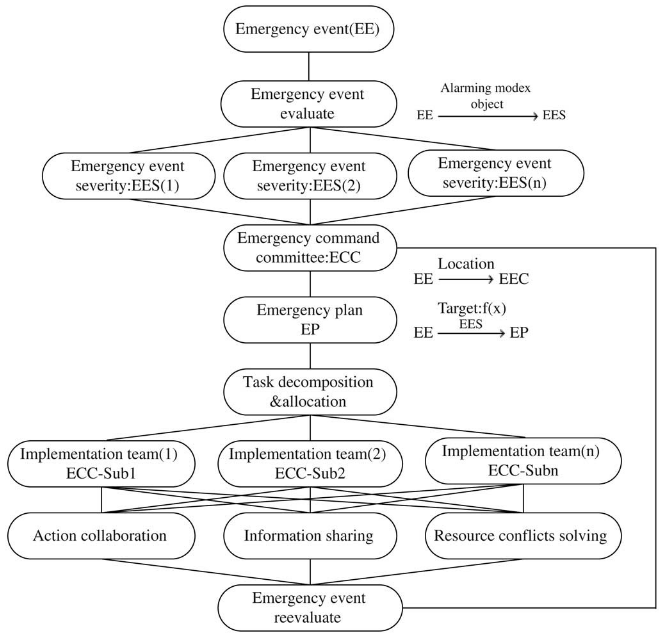

Fig. 7. Process of emergency decision-making.

Time and location will be related to the determination of the members in the task groups. For instance, if an EE had occurred in Shanghai, then the task group members would be better coming from Shanghai. Similarly, if the EE had occurred at night, task members would be those on call.

Definition 5: Emergency Event Severity Class $\mathrm{EES} = \mathrm{EE}(x, \mathrm{Object})$*:*

$$EE \overset{\text{Alarmingmode:xobject}}{\rightarrow} \text{EES}. \tag{1}$$

EES denotes the result of EE evaluation. x denotes the alarm mode. For instance, in China, calling "*110*" would be the alarm mode, which means the police would be involved in the interference of the EEs.

Definition 6: Emergency Command Committee $\mathrm{ECC} = (\mathrm{head}, (\mathrm{ecc}-\mathrm{sub1}, \mathrm{ecc}-\mathrm{sub2}, \ldots))$*:*

$$EE \overset{\text{Location}}{\rightarrow} \text{ECC}. \tag{2}$$

ECC denotes the group of emergency decision-making and commanding. In emergency handling, distinct division and cooperation is significantly important. Different kinds of EEs correspond to different administrations and professions. In the meantime, it would be efficient if the members of *ECC* are selected from local agency where EEs happened.

Definition 7: Emergency Plan is denoted asEP:

$$EE \overset{\text{Target:f(x)EES}}{\rightarrow} \text{EES}. \tag{3}$$

In order to take quick and effective reactions to emergency events, designing multiple plans in advance based on the severity class of the EE is desirable. The target involves with the utility function $f(x)$ in the decision-making process.

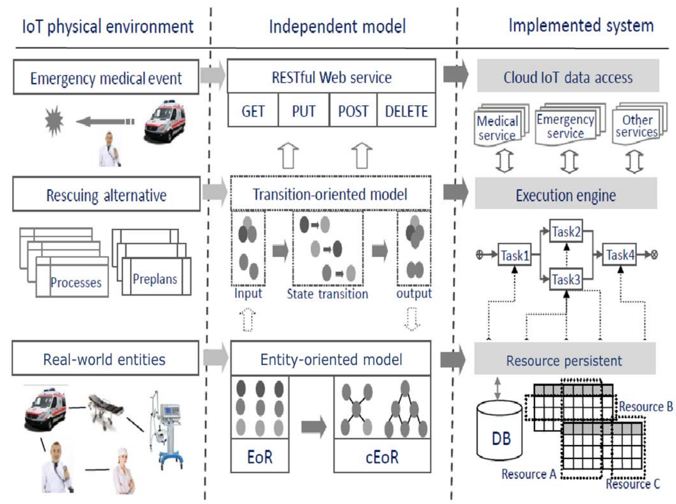

Fig. 8. Implementation of UDA-IoT in emergency medical DSS.

In our approach, physical resources, such as task groups and vehicles, as well as data resources, such as the medical records of the patients, are maintained by the RESTful services management modules. These resources are specific to the location where the emergency events occur.

When emergency events occur, resources are loaded into emergency decision-making platform to facilitate a dynamical decision-making process, according to the location and the severity level of the emergency events.

In this emergency decision-making process, online information sharing is important for decreasing information uncertainty. Thus, information resource ubiquitous accessing component is the key point in the DSS architecture. According to our proposed ubiquitous IoT data model, two types of resources are managed, which are entity resources and data resources. *Entity resources* refer to traditional physical resources, including staffs, medicine, ambulance, and medical apparatus. *Data resources* refer to the data generated by IoT or recorded in databases, such as the electronic medical record of the patients, which are significant to decision-making. Resources can be composited to more complicated resources. The resource control mechanism encapsulates the resources into RESTful-based Web services to be registered, retrieved, and used by application systems.

B. Implementation of Ubiquitous Data Accessing in Emergency Medical DSS

In medical decision-making, an EE is divided into multiple subtasks, which corresponds to multiple rescuing actions, each of which needs to use several types of physical resources to fulfill the emergency preplans. Therefore, in IoT medical systems, the emergency decision-making process involves the integration of the physical resources and the rescuing preplans. Hence, in the implementation of the IoT application systems, entities, events, and business process exist in the real world need to be mapped into the information environment, as shown in Fig. 8.

As shown in the left column of Fig. 8, the real objects in IoT physical environment are mapped to Platform Independent Model (PIM) [23], including entity model, transition model, and RESTful interface. In detail, according to the definition of EoR in Section III-A, the real-world entities are firstly mapped to EoR resources. Then, according to business requirement, EoR resources are composed to cEoR resources. For instance, EoRs of *breathing machine, stretcher, oxygen tank*, and *medical monitor* can be composed to a cEoR resource. According to the definition of the transitive resource, the rescuing process and the preplans can be transferred to transitive resources. Usually, the business process or preplans include several combined operations of multiple information entities, so that the business process often is composed of more than one transition resources. Besides, each transition resource provides standard RESTful services interface to application systems, and the business process can be executed through accessing RESTful service interfaces sequentially.

In order to implement application systems, PIM needs to be transferred to Platform Specific Model (PSM), as shown in the right column of Fig. 8. Information entity resources are transferred to the reference of the data sources. An EoR resource might be an entire reference to a database table, or a reference to several fields in one database table, as shown in the following:

$$\mathrm{implement(EoR)} := \mathrm{reference(table(column))}.$$

A cEoR resource is the integration of multiple databases. Data in a cEoR resource may come from different data sources, which is shown as follows:

$$\mathrm{implement(cEoR)} := \mathrm{reference(datasource(EoR))}.$$

The transition resources based on EoR/cEoR are transferred to the tasks in the application systems. Each task contains the controlling to the status of EoR/cEoR. The business process is fulfilled by executing subtasks in sequence, as shown below:

$$\begin{aligned}&\mathrm{implement(ToR)} := \mathrm{Task(Transition(EoRs/cEoRs))}\\&\mathrm{implement(Process)} := \mathrm{Invoke(ToRs)}.\end{aligned}$$

Each business process provides its service accessing interface to the application systems through *HTTP* protocol.

Fig. 9 shows the interface of the emergency medical DSS using UDA-IoT.

In Fig. 9, various types of information are accessed timely and displayed in the same screen, so that decision makers can get an all-round view of the development of the emergency event and the status of the rescuing resources to take rapid actions.

C. Discussion

As demonstrated in the case study, the emergency decision-making is an iterative and evolution process. Decision makers need to collect resources for rescuing quickly and adequately. UDA-IoT uses IoT to locate the ambulances and the medical staffs in a mobile environment. The resource model used in UDA-IoT also provides the foundation for distributing patient data across hospitals on-demand.

Emergency medical rescuing process can involve multiple types of resources. The coordination of multiple resources is complex. In our method, we use cloud computing platform to coordinate data across organizations [24], [25].

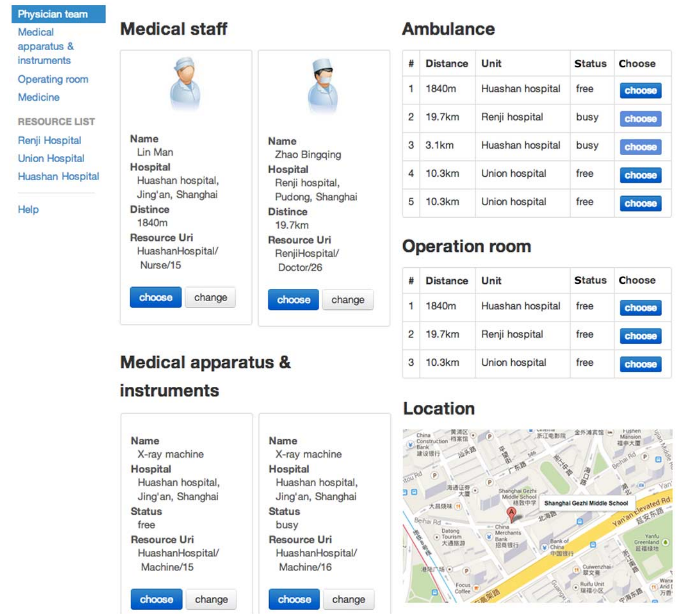

Fig. 9. Program interface of the emegency medical DSS.

TABLE I
COMPARISON OF OUR METHOD WITH SEVERAL OTHER GDSSs

Features	UDA-IoT	Emergency DSS [22]	MECDSS[23]	Mobile DSS [24]
Data model	Resource model	MySQL	Data warehouse	Fuzzy preference relations
Business process management	√	×	√	×
Heterogeneous data integrating	√	×	√	×
Development methodology	MDA	Knowledge-centered	Activity-centered	User-centered
Mobile computing	√	×	×	√
Software architecture	Restful	Java EE	SOA	M-Internet

We compared our research work with several other inter-organizational group decision support systems (GDSSs), as shown in Table I.

In Table I, the comparison result shows that various types of methods are adopted in the development of the DSSs, including Model-Driven Architecture, knowledge-centered [26]–[35], activity-centered and user-centered, to support inter-organizational cooperation. With the use of smart devices, mobile computing is an important feature in today's decision support systems [36]. Data models, which can support data access efficiently and conveniently, play critical roles in the architecture of the mobile DSSs.

V. CONCLUSION

Innovative uses of IoT technology in healthcare not only bring benefits to doctors and managers to access wide ranges of data sources but also challenges in accessing heterogeneous IoT data, especially in mobile environment of real-time IoT application systems. The big data accumulated by IoT devices creates the problem for the IoT data accessing. Our study provided three main results.

1) It is concluded that IoT is useful in data-intensive industrial applications because it provides a platform to access large scales of data sources in mobile application environment [37]–[41]. With IoT, users can collect more data, which are important to industrial applications such as medical services. Using the data picked up by the IoT devices, managers and analysts can conduct better business analytics.
2) Methodologically, we demonstrate how the heterogeneous IoT data can be accessed ubiquitously. In many IoT applications, smart objects are manifold and moving, so that ubiquitous data accessing is critical to IoT data analysis. Resource-based data model can support accessing data cross-platform by URI through Web for IoT applications.
3) We highlight the use of UDA-IoT in emergency medical services. In emergency medical services, data of patients, doctors, nurses, and ambulances can be collected by IoT notes and transferred to cloud computing platform. In UDA-IoT model, heterogeneous IoT data are encapsulated in unified format of resources with unique URI so as to be accessed ubiquitously. The UDA-IoT is significant to support decision-making in emergency medical services.

In this paper, we focus on unified data model and semantic data explanation by ontology in data storage and accessing. New challenges may exist in industrial sectors involved with long supply chain [42]–[47]; as in these sectors, large numbers of companies are involved and the industry ecology becomes complex. As such it is difficult to apply an unified data model to the entire supply chain. The proposed UDA-IoT method is suitable for information-intensive industries, such as healthcare, in which relatively short value chains are involved that are suitable for applying standard data models through the entire business process.

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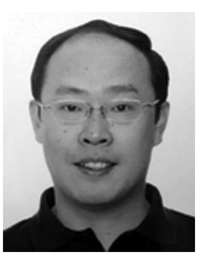

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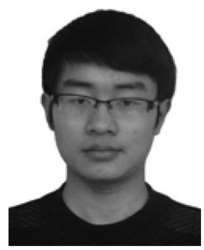

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