Open Information Gateway for Disaster Management

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***Abstract*—How to exchange information between parties in a mega-scale disaster management system is one of the fundamental challenges to support timely and efficient disaster response and relief. Specifically, the timeliness, scalability, and availability are three desirable features for information exchange. We call the framework to support information exchange with the three features an open information gateway, OIGY in short. In this paper, we present the challenges of information gateway, and the design of the communication protocols and the fundamental components and algorithms to support the aforementioned features. The efforts of this work will be divided into two major components: one is the distributed Truthful Real-time Information Publishing and Subscribing (TRIPS), and the other one is Heterogeneous And Plug-n-PlaY networks (HAPPY). The two components in OIGY collaborate to provide reliable and timely information publish and subscription service. TRIPS is responsible for logical information exchange management. Compared to modern real-time publish and subscription services, TRIPS aims on information responsiveness and distributed content-based filtering in an un-reliable network. To achieve better responsiveness, TRIPS will take advantage of the run-time service composition of SOA framework to select information sources. To enhance the success rate, TRIPS relies the information routing information provided by HAPPY. HAPPY will integrate heterogeneous communication networks including 3G/WiMAX telecommunication network and mesh mobile network into a coherent communication network and discovers the routes with probabilistic bandwidth guarantee.**

I. INTRODUCTION

Success disaster response requires the collaboration from many parties including telecommunication service providers, web service providers, general publics, rescue agencies, and rescue coordinators. When disaster occurs, how to exchange information among victims, rescuers, and decision makers is one of the most critical challenges. The goal of this work is to design and prototype a distributed information gateway to enhance responsiveness and availability of information exchange for disaster response.

In the last few decades, many attempts aimed on developing special communication devices and reserving specific communication channels for disaster rescue. Examples include satellite phones[1], IP-based 911[2] and rescue radio[3]. However, the applicability of these new technologies was founded limited. Take satellite phones as an example. Satellite phones provide location-free communications no matter whether the users are located in mountainous area, metropolitan, or on the sea. It is extremely effective for rescuers in mountainous area and sailors on board. Due to its high deployment cost, it is not possible to put a satellite phone in every emergency kit. In addition, it requires regular maintenance to assure its functionality. In the mountainous area of Taiwan, every village is equipped with one satellite phone for emergency use. However, due to poor maintenance, the batteries were mostly dead and many of the phones did not function at all during 2009 Morakot typhoon [4].

The experience in last several disaster rescue efforts show that how to effectively make use of all available communication devices and services is the key to a success rescue effort. During Haiti earthquake [5], the victims trapped in the damaged buildings sent text messages via their cell phones, which allow the rescuers to locate them in the left-behind area and save more than 60 victims. During 2009 Morakot flooding in Taiwan [4], the destroyed communication infrastructure prevented the victims from contacting their family members and rescue agencies. However, their family members posted on plurk and twitter that the victims were not reachable, and marked their possible locations on maps.google.com. The information were broadcasted by phones and social network web services. Consequently, the rescue team was able to locate the victims, and provided food and water supply to the victims. This information exchange model was proved to be effective for disaster response. However, such a success rescue requires both effective coordination and timely intelligent information, which were conducted by experienced rescuers and/or crowd sources.

We call an information exchange framework that are designing for collecting, fusing, and distributing information during disaster management the *information system for disaster management*, and refer it to *ISDM* for short. An ISDM is capable of making diverse, multi-domain data and information generated by independently developed intelligent things and from people less fragmented and more trustworthy, delivering the information to independently developed disaster management applications and services with high availability and on a timely basis, and supporting different usages of the information for disaster preparedness, response and relief purposes and for research and planning in disaster reduction. The system can also adapt to needs, evolve and grow in capabilities with scientific and technological advances and can readily accommodate new information sources, applications and services as needed in response to unforeseen crisis situations.

An effective ISDM replies on many ICT (Information and Communication Technologies) components such as data repositories, fusion of symbiotic information, and information exchange. In this paper, we are interested in information exchange services in ISDM. To support effective rescue, the system must take into account the timeliness and run-time service composition for information exchange. In a disaster area, the physical and network infrastructure may be severely damaged or simply unavailable. On the other hand, before issuing rescue operations in response to urgent disastrous situations, acquiring current and accurate data will be the most critical operation. In general, data are collected from a collection of pre-installed or quickly-deployed sensor devices, monitoring stations, satellite images, as well as civilian witness reports. Each of the data sources has its individual characteristics of physical properties (e.g. proximity of observation location), temporal properties (e.g. how often data are reported), numerical properties (e.g. sensitivity capability), and even rational properties (e.g. observations under human emotional stress). An ISDM must be able to select and integrate multiple data sources into a coherent information service. Hence, how to discover and compose information service in an efficient manner is a major challenge for ISDM.

It is evident that the research community and industry should continue their attempts to develop new sensing technology and affordable communication devices for disaster rescue. In the meantime, how to assure that existing and widely available (tele-)communication devices can be federated into the disaster management systems in harmony is critical to rescue efforts. Hence, this work aims on how to recover the communication network to assist victims and rescuers to communicate with the others in the disaster management system, how to orchestrate the information to reach their destinations, and how to acquire the information in timely manner. In short, the work aims on develop *Open Information Gateway*, called *OIGY* for short, which is an distributed middleware to support information exchange during disaster response.

The remaining of this paper illustrates the preliminary study and design of Open Information Gateway. In Section 2, we will illustrate the desired features of Open Information Gateway, its challenges, and related works. Section 3 illustrates the system architecture and design of Open Information Gateway. Section 4 discusses the work to be completed in the near future.

II. Desirable Features, Challenges, and Related Works

The information exchange services for disaster management has three desirable features: *scalability*, *timeliness*, and *availability*. In the following, we present the significance and challenges of these three desirable features. We will also discuss the latest developement on these three desirable features.

Many of modern information exchange services are (either *logically* or *phyislcally*) centralized to reduce maintenance efforts. Client-server and web-based services are two typical examples of centralized services. This type of information exchange services have unified view of data and are easy to maintain; it also provides a single service point and provides better usability for the users. There are no doubts that this service model has its own merits. However, this service model highly depends on a reliable and robust network infrastructure so that the users can reach the service point. During a disaster, it is difficult, if not impossible, to have reliable and robust network connection. In addition, the type of services does not scale up. Although most of modern information exchange services make use of distributed architecture to share the load, none of them are designed to be scaled up in a short time window and to provide service for bursty requests.

To achieve scalability, information exchange services must be designed as distributed information services. A distributed information exchange model allows ISDM to provide information exchange service when only parts of communication infrastructure is available. In addition, it also eliminates the bursty requests sent to a central portal. Publish/subscription model is proved to be effective and efficient for systems that need repetitive, time sensitive data/message distribution. A publish/subscription system is comprised of information producers who publish and information consumers who subscribe to information. The key benefit of publish/subscribe for distributed event-based processing is the natural decoupling of publishing and subscribing clients. This decoupling can enable the design of large, distributed, loosely coupled systems that interoperate through simple publish and subscribe-style operations. Distributed publish/subscription systems are well-suited to handle large numbers of events occured in large area networks. Distributed publish/subscription services do not rely on central publish and subscription services. The subscription requests are processed by pub/sub brokers located on different network locations, rather than centralized publicaiton server. Consequently, distributed publish/subscription services can meet the scalability requirement of information gateway. PADRES [6], [7] and Web Solutions Platform Event System [8] are examples of distributed publish and subscribe services. However, modern distributed publish/subscribe services aim on distributing the information exchnage services in the network and still rely on reliable network to provide a static network of pub/sub information brokers. When some of the brokers are either disconnected from the network or out of service, part of the services become unavailable. While managing disaster, the network is neither reliable nor robust. Hence, the network of pub/sub information brokers must be dynamically formed. In addition, modern distributed publish/subscribe services do not balance or share the publish and subscribe requests on the broker. While managing disaster, the network can be congested or disconnected. Without managing the loads on the brokers, the services can have poor performance.

Timeliness means that the information should be delivered within a given time interval. Most, if not all, of messages for disaster management are either time sensitive or time critical. Hence, timeliness is a critical requirement for information exchange in disaster management. Although the granularity of timeliness requirements for disaster management is much greater than that for safety critical systems, the outcome of late information exchange are also vital.

The challenge for timely message delivery includes the dynamics of network connectivity and capacity, and heterogeneity of information publisher and subscribers. During the disaster, the communication capacity changes from time to time. At the disaster area, communication uplink may become a rare resource for all the victims and rescue workers. When the network capacity decreases and message deliveries are blocked, the users and messaging protocols such as TCP tend to retransmit, which could further damage communication infrastructure. Without being aware of the dynamics, a greedy message publishing service will soon jam the network and bring down the link. How to deliver the message via proper communication uplink so as to meet the timing requirement is a challenge. Although web service is now a well-accepted service interface, not all the devices are compatible with web service. In many disaster occasions, broadcasting the message by radio is the most effective manner to deliver the message to the general publics; phone call is the most effective manner to a family member on the other side of the earth. How to integrate the heterogeneous communication networks so as to compose a coherent information exchange service is certainly another challenge.

Real-Time publish/subscribe services extend publish/subscribe services to deliver messages in a given time interval. Real-time publish/subscribe well suits for the system with static network environment. One example is to use AMQP for stock exchange in Wall Street. Deng etc. [9] evaluated several real-time publish/subscribe service in QoS-enabled component middleware. This work empirically evaluates the performance of a container-based design and compare it with mature object-oriented real-time publish/subscribe implementations. One issue in most existing architecture that support publish/subscription is their limited support for the expression and enforcement of Quality of Service parameters (such as required latency, reliability, etc.). This is a significant shortcoming for existing architecture, which was addressed in this work. However, in the disaster management, the communication infrastructure changes over time. Existing systems do not address the change of communication infrastructure and will be address in our work.

Availability refers to the availability of communication network, which is the most critical feature for ISDM. In this work, we also aim on recovering the communication network to connect the remote sensors, victims, and on-site rescuers with support teams. The rescue efforts in the last few disaster worldwide show that we should not rely on single type of communication network and have to integrate heterogeneous communication network to a coherent communication network. For instance, rescue personnel, mobile users, or tracked objects might move around the monitoring area. Long-range communication might be destroyed by the disaster. Hence, we need a flexible mobile infrastructure to cope with such uncertainty and temporary failures.

In recent years, wireless mesh networks (WMNs) [10] have been developed to provide wireless broadband connectivity. A static MWN is composed of stationary wireless routers, which help forward data for last-mile clients to the Internet. A number of works [11], [12] have investigated how to utilize multiple channels and multiple radios to enhance the capacity of a WMN. However, for a rescue system, such a static infrastructure cannot adapt its network topology to dynamic mobility of clients (e.g., rescuers) or objects of interests. Hence, the focus of this project is to develop a mobile mesh infrastructure that adjusts its topology and maintains the connectivity among clients.

On the other hand, in a sensor network, a large number of sensors are distributed in a target field to perform sensing of events of interest. Several works, such as [13], [14], have investigated how to deploy sensors such that each point or objects of interest in a field can be sensed by at least a sensor. The above problem is usually referred to as the sensor cover problem. Some studies [15], [16] then solve the problem with consideration of the lifetime of a sensor network. They attempt to activate only a subset of sensors to perform the sensing task, while also guarantee the sensor coverage. Another type of sensor networks collects data using data mules, which are mobile devices that can move dynamically to cover various areas. Previous works [17], [18] study how to determine the speed and the trajectory of data mules such that the mules can traverse a minimal path length, while still cover the entire area of interest.

Conventional auto-configuration solutions for traditional IP networks [19] cannot be applied to mobile ad hoc networks, because they assume all nodes are connected and address queries can be achieved by single-hop broadcasting. To facilitate auto-configuration in multi-hop networks, the first approach was adaptations of auto-configuration protocols for traditional IP networks, but a serious drawback of this approach is that network partitioning and merging is not supported. A similar approach is discussed in [20], which supports network partitioning and merging by periodically repeating the DAD; however, the drawback of this scheme is the maintenance cost of its hierarchical addressing model. Finally, the Weak DAD (WDAD) scheme [21] adds a key of an arbitrary length to each address distributed by the protocol, and the probability that a conflict cannot be detected decreases with increasing key length. However, on the down side, the protocol overhead increases with the key length.

III. Design of Open Information Gateway

To support aforedmentioned desired features of information exchange services, we proposed to design and prototype an information exchange service framework, named *Open Information Gateway* (OIGY), to support distributed timely information exchange over heterogeneous networks. In this section, we present the methodology and advantages of each component in the system and how they interact with each other.

All the OIGY services will be executed on the edge devices in the network, including computationally weak devices such as cell phones and mud sliding sensors, and computationally powerful devices such as weather forecast service on cloud servers and data repository server in data center. Figure 1 illustrates the deployment of OIGY and software architecture of OIGY. As discussed earlier, numbers of individuals, news agencies, government agencies, and rescue agencies form the disaster management system. Each of them can be the providers and consumers for the information. For instance, data center in government agency can subscribe information from sensors in disaster area and publishes the fused/verified data to crowd sources. Victims in disaster area can publish their messages to the others and can subscribe information from their family members and government agencies. To achieve scalability, OIGY will be deployed as a middleware software component at each agency. For victims, an OIGY widget can be installed on their cell phones; for weather forecast agency, an OIGY service can be installed on their computationally power server. In addition, OIGY can also be distributed installed on Point-of-Service devices, which are located on supermarkets and convenient stores to publish and subscribe information. To deploy OIGY, minimal amount of software repository servers will be deployed to provide the middleware components for edge devices. However, these servers are not designed to provide any run-time service during disaster rescue.

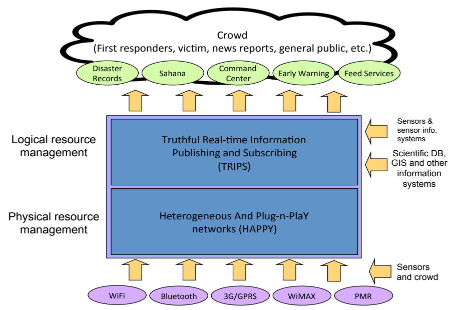

Fig. 1. System Architecture of Open Information Gateway (OIGY)

Open Information Gateway (OIGY) consists of two major components: one is the distributed Truthful Real-time Information Publishing and Subscribing (TRIPS), and the other one is Heterogeneous And Plug-n-PlaY networks (HAPPY). The two components collaborate to provide reliable and timely information publish and subscription service. The objective of HAPPY is to interconnect all network-capable devices using all kinds of possible manners, which may be comprised of heterogeneous network access technologies (e.g., WiFi, Bluetooth, Professional Mobile Radio (PMR), and 3G/GPRS) using different approaches (e.g., Infrastructure-based networks, wireless mesh networks, mobile ad hoc networks, and opportunistic networks).

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Figure 2 illustrates the architecture of dynamic service composition and distributed information exchange. Compared

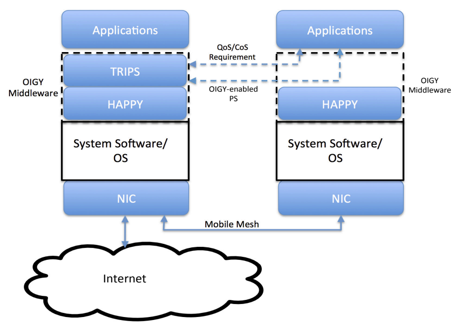

Fig. 2. Distributed Information Exchange in OIGY

to traditional publication and subscription services, the users in disaster management may not have the luxury and chance to the proper information sources. During the disaster, the volunteer tend to help to provide information in different formats. To take into account the dynamics and heterogeneity of the information services, TRIPS will take advantage of the SOA architecture to compose coherent information service. Based on our previous work on QoS management framework designed for SOA, we may treat each data source as a deployed service in SOA and map the data integration procedure as a service. With the dynamic service composition, TRIPS will be able to discover the publisb/subscribe service when only parts of the communication network is available.

IV. SUMMARY

ISDM plays a critical role in disaster management. We proposed to design and prototype an open information gateway (OIGY) so as to delivery timely information in a distributed manner over heterogeneous networks. In OIGY, HAPPY and TRIPS are designed to manage physical and logical network resource respectively. In addition, they are designed with the unreliable and heterogeneous networks in mind.

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