RIM: Resilient Information Management System in Network-Isolated Environment after Disasters

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I. Executive Summary

In this project, we design and implement a resilient information management (RIM) system, which is applicable under network-isolated environment. RIM can be setup immediately after disasters to serve people as an information collection and distribution system in disaster area, despite of the Internet unavailability.

RIM consists of several distributed information centers, each of which is capable of computation and wireless communication covering a limited area. We also develop smartphone Apps that can be installed on both iPhone and Android-based smartphones. Users can use the smartphone App to create HELP, SOS or medical triage messages, request/demand resources (e.g., water and food), report dangerous places, and chat with other users. Since we consider an environment without Internet and cellular networks after disaster, we enable the Bluetooth communication between smartphones for message dissemination. For the communication between smartphones and information centers, WiFi is used. To provide low-delay, flexible, and low-cost network services, we also integrate Unmanned Aerial Vehicles (UAVs) into the system. To fulfill the designated target, we develop customized UAVs (e.g., drones) equipped with wireless communication capability and data storage. They are controlled by the server to provide network services for disaster management. The network services include broadcasting latest news and evacuation instructions, forwarding triage and HELP or SOS messages from users to server, maintaining network connection among members within a rescue team. This integration can enhance the system built on ad-hoc network by reducing delay and providing more network services. RIM has the following distinguishing features:

- **Internet Independency**: RIM is specially designed to operate without the Internet and therefore can function well even in the absence of Internet.
- **Self-sufficiency**: Once RIM is set up, it not only automatically gathers and distributes important information to residents, but also makes certain decisions or suggestions (e.g., material allocation, rescue actions schedule) using the gathered information.
- **Cost Efficiency**: At first, RIM does not require expensive dedicated hardware deployment. Secondly, the information collection process relies on the cooperative participants of all the local residents and volunteers, without intentional labor cost.
- **User Friendliness**: RIM system can be set up quickly after a disaster happens. Furthermore, the client developed for smartphones is also designed in a friendly way that it can be easily used by any people.

The ultimate goal of RIM is to provide self-organized cooperative rescue to workers and local residents with detailed people-centric information in the disaster hit area where Internet is broken down. RIM can also contribute to establishing a cooperative community by sharing information among disaster victims. Moreover, we develop such a system by integrating the UAV technologies with the ad-hoc communication mechanism. We

will evaluate all developed protocols and algorithms with respect to the described performance metrics and validate them using testbed-based networks ranging from small to large scale.

II. General Description

In this section, we first present the computation and communication architecture of RIM. Then, we present four main functions provided by RIM.

A. Computation and communication architecture

Fig. 1 shows an overview of the RIM system. By introducing a movable (Information and Communication Technology) ICT-unit in each area, we can construct an *information center* that is able to serve the residents, volunteers, and rescue teams with essential information (Details about the ICT-unit can be found in *http://mdru.org/*). Multiple information centers distributed in different geographical regions can synchronize by employing smartphones and UAVs for data exchanges.

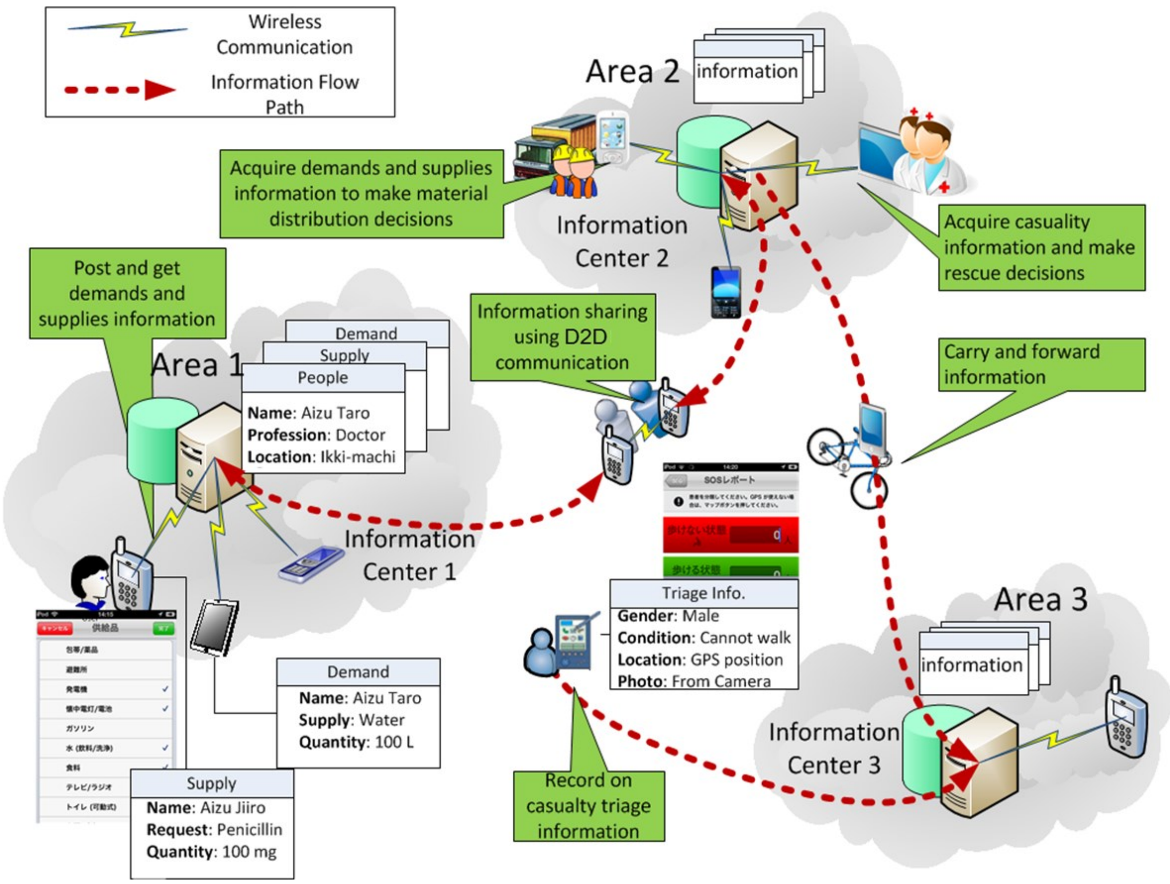

Figure 1. System Overview

To implement such a resilient information management system, we deal with the following issues.

1. **Basic Communication Infrastructure:** We first need to build a wireless network infrastructure that can provide communications without Internet. Here, we call the communication functions and data sharing functions realized by the movable ICT-unit developed by NTT as an "information center". Both WiFi-based wireless communication and a Linux server are available on the ICT-unit. Once a user enters the service area of an information center, he/she can communicate freely with the server or the other users within the

same server's wireless coverage.

2. **Uniform and Friendly Client:** The data in each information center are maintained and shared by all participants, e.g., local residents, governors and volunteers. Accordingly, a friendly client that allows any people to easily share and acquire information from the servers shall be developed. To deal with the diversities of smart devices, the client shall support different platforms, e.g., iOS and Android.
3. **Uniform Database System:** The servers in the information centers are responsible for reserving various salvation information such as food, clothes, medicines, health conditions of residents, volunteers' skills and locations, etc. A database system shall be adopted. The data structures and descriptions for all possible information to be used in the databases shall be defined. All the ICT-units will be integrated with such databases in a uniform format such that the data can be shared among different information centers. The databases will play an important supporting role in the RIM system.
4. **Smart Decision-making Module:** Besides reservation of these data, RIM system shall be also able to match the material supplies and demands fairly and efficiently or provides suggestions to the rescue activities according to the gathered casualty information. To this end, after the implementation of the database system, an information analysis and decision making module shall be developed on the server side.
5. **Intermittent Server Synchronization:** Although the information centers are distributed in some isolated areas, they are not independent. If the information between these databases can be synchronized, more valuable information will be available in each information center. Due to the lack of continuous Internet connection, we cannot synchronize them in real time. Instead, we plan to design an intermittent synchronization method by introducing the smartphones moving between different information centers as the inter-server communication media. A client can automatically download some data from a server and upload them to another one. The whole process does not require special involvement of people. Furthermore, observing that device-to-device (D2D) communication capabilities like Bluetooth are available in most mobile devices nowadays, RIM will explore such capabilities to improve the synchronization efficiency.

Also, as shown in Fig. 2, we integrate UAVs into the system to enable two-way communication between servers and users, and provide local network service for rescue teams. To fulfill the designated target, we develop customized UAVs (e.g., drones) equipped with wireless communication capability and data storage. They are controlled by the server to provide network services for disaster management. The network services include broadcasting latest news and evacuation instructions, forwarding triage and HELP or SOS messages from users to server, maintaining network connection among members within a rescue team. To efficiently provide these network services, we will address challenges, such as how many drones do we need in a certain disaster scene, and how to make the energy-efficient travelling routes for a drone when we use it to collect and deliver the messages. Also, the customized drones can sense human by detecting signals from their smartphones, so that we can search victims even they are buried under collapsed buildings.

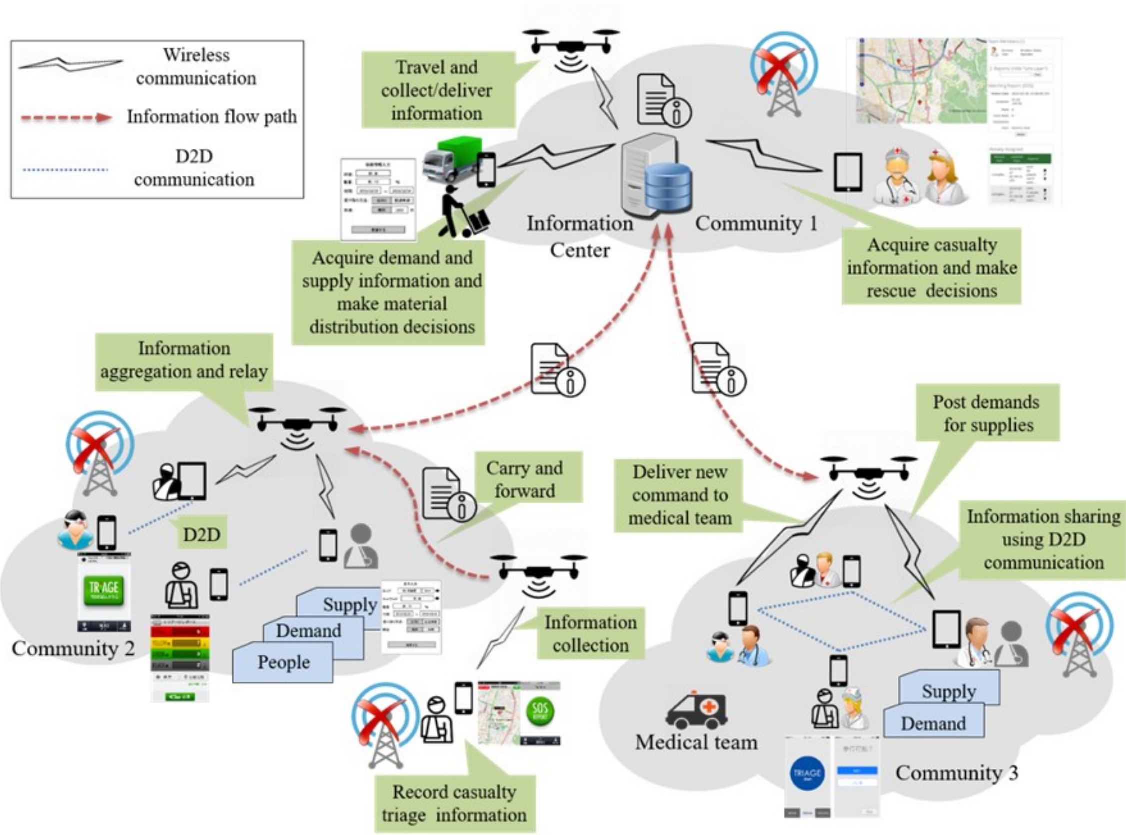

Figure 2. Overview of the UAV-based RIM system

B. Main functions of RIM

Based on the computation and communication architecture shown in Fig. 1, we develop several key functions as shown in Fig. 3. Information gathering refers to collect information from all volunteers and store the data into the database. Information enquire provides information query service (e.g., supplies lookup, casualties search, etc.) from the server to the mobile applications. Decision making is about intelligent resource management and rescue activity scheduling. Information transfer is required for the data synchronization between the isolated information centers. All the modules require interactions between both the server side and the client end.

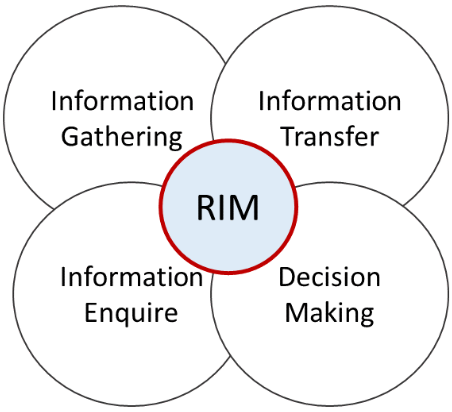

Figure 3. Design concept and key functions of the RIM system

III. Technical Solution and Project Details

To cope with the Internet unavailability problem that we may encounter after a disaster happens, NTT laboratory has designed a system called ICT-unit, which can be quickly set up in disaster areas to form a basic wireless network infrastructure. As shown in Fig. 4, an ICT-unit is embedded in a cargo with length 3.6 meters and total weight 3.4 tons. It does not occupy large space and is convenient for storing and carrying. Table 1 summarizes some key ICT-unit specifications. Besides the basic wireless communication capability, an ICT-unit is also integrated with two Linux servers. Therefore, certain services can be directly implementd onto an ICT-unit, e.g., the diaster information management system for our project. By WiFi communications, the service provided by an ICT-unit can reach to hundreds of meters. Any devices with WiFi communiction can connect to the ICT-unit to get the provided services. An ICT-unit provided by NTT laboratory will be deployed in the campus of the University of Aizu on July, 2013. Therefore, our main task in this subject is to set up the ICT-unit in our campus and to be familiar with its operations, on both the servers and the wireless communication. A simple testing application in server/client architecture, e.g., file transferring between the server and a mobile phone, will be developed. This will build us with the basis to use the ICT-unit in the following development tasks.

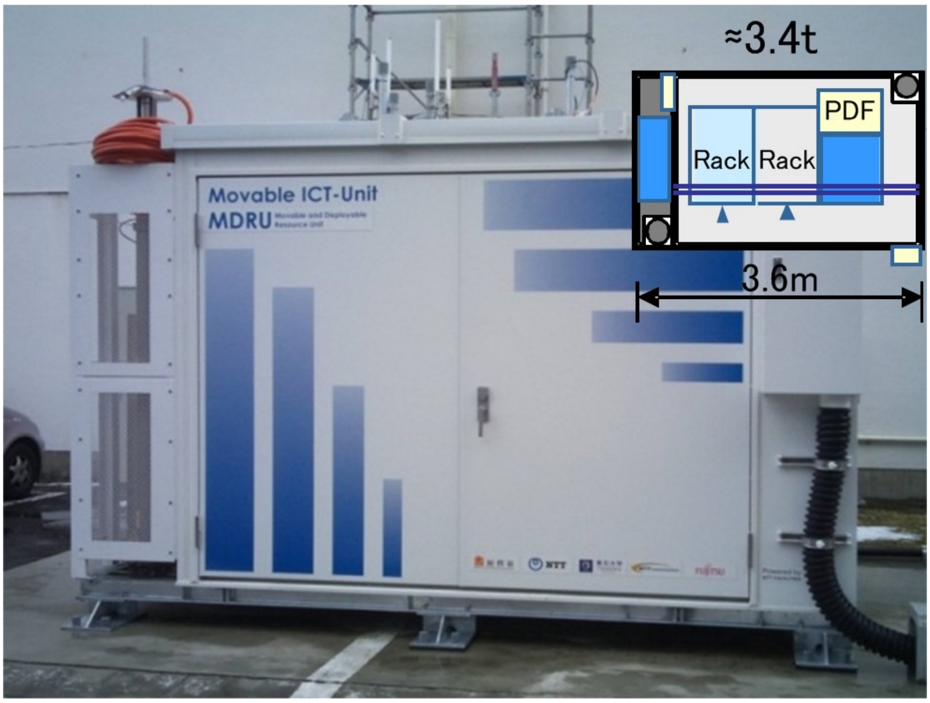

Figure 4. Outlook of an NTT ICT-unit

Table 1. Specifications of an ICT-unit

Size	**W 3.6 m × D 1.8 m × H 2.5 m**
Weight	**Container: 2 Ton** **UPS, Air conditionor, Rack: 1.36 Ton**
Number of racks	**2 (19-inch rack)**
Maximum power supply	**16.8 kW**

For backbone technologies, there are two unique technologies developed independently: a network infrastructure named “movable ICT-unit,” and a smartphone application named “DMA” (Disaster Management Aid). By combining two advanced technologies, we can realize a powerful and useful ICT system to support people in disaster-hit region even when the Internet is broken down. To tackle the data synchronization issue between servers in different areas, a cooperative opportunistic “carry-and-forward” data forwarding protocol using D2D communications will be designed and developed.

To construct the UAV-based RIM system, we will develop a customized drone with three working modes, each of which can provide a different network service.

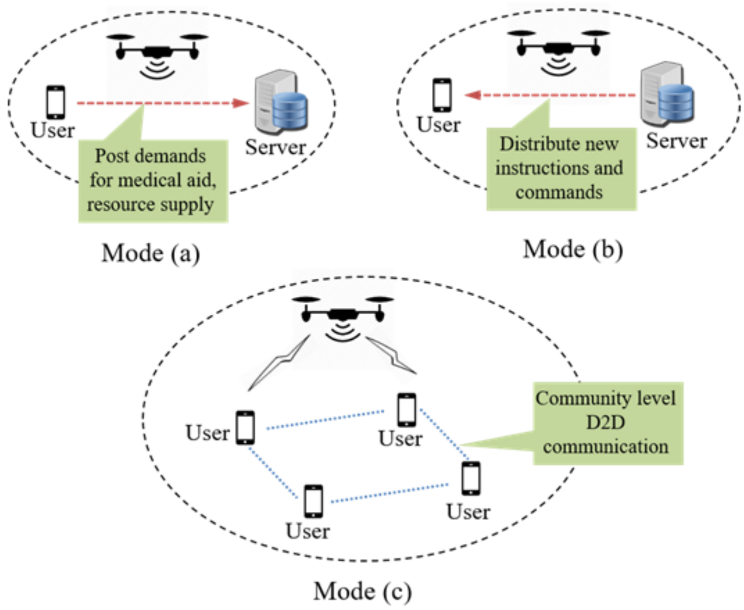

Figure 5. Three modes of communication in the drone-based RIM system

1. Data collection mode:

As shown in Fig. 5 (a), UAVs working under the data collection mode can forward triage and HELP or SOS messages generated from RIM apps to the server. UAVs’ trajectory is designed by the server. They are sent out to collect RIM messages from smartphones along their trajectories. After UAVs are back to the server, they upload collected data to the server, and recharged for next-round of message collection. In order to maximize the efficiency of data collection, trajectories of UAVs should be carefully designed. The UAVs are powered by carried batteries or fuel with limited capacity. The number of RIM users covered by their trajectories should be maximized. We will develop new algorithms for UAV trajectory planning with the objective of maximizing the number of located people under the energy constraint of UAVs. An additional challenge is that it is hard to design an optimal trajectory before sending out an UAV without the information of real-time human distribution. To conquer these challenges, we design a two-stage UAV trajectory planning algorithm. In the first stage, i.e., before sending out UAVs for localization, we design an initial trajectory using the approach of motion planning, which is widely used for robotics, according to an estimated RIM user distribution and geographic information. In the second stage, i.e., after sending out UAVs, we design a real-time searching algorithm based on close-loop control theory, such that UAVs can adjust its trajectory according to the detected user distribution during its flying. Formally, the control process can be described as:

$$Y(s) = \left(\frac{C(s)}{1 + F(s)C(s)}\right) R(s),$$

where R(s) and Y(s) are the Laplace transform of current trajectory input function and real-time trajectory output function with variables of time. C(s) means the control of moving speed and direction, and F(s) means the human distribution feedback from SAR-based localization. Based on this design, if some UAV finds that there are many RIM users at some regions, it changes the trajectory and spend more time here; otherwise, it quickly move towards other regions. This design can efficiently handle the uncertainty of RIM user distribution in disaster environment. The performance of our proposed flying trajectory algorithm will be evaluated by both simulations and experiments.

2. Data dissemination mode:

UAVs working under the data dissemination mode can broadcast latest news, evacuation instructions, and commands to medical teams in different regions, as shown in Fig. 5 (b). It is ideal to deploy a dedicated mobile station for each community to achieve full coverage. However, many mobile stations are needed since the number of communities can be large in practice, leading to high cost for constructing such a disaster management network. We face a challenge of using a limited number of mobile stations to achieve efficient disaster management. Also, working capability of mobile stations is constrained by batteries or fuel carried on. An intuitive idea is to let mobile stations periodically travel around multiple communities. This approach is far from efficiency because it ignores real-time task generation from disaster management center. Another challenge is that disaster management tasks are generated in real time. It is difficult to predict future tasks since they are affected by many factors including environmental changes, rescue policy, and demands from various facilities. To enable efficient disaster management, we propose to design an online algorithm that schedules mobile stations for disaster management tasks with weights, without any knowledge of future task arrivals. Our objective is to maximize the total weight of finished tasks under constraints of maximum working capability of mobile stations. Since it is impossible to finish all tasks with a limited number of mobile station at each time slot, we propose to conduct important ones with higher weights.

3. Local Area Network (LAN) mode:

As shown in Fig. 5 (c), UAVs working under the LAN mode can provide network collection among members within a medical or rescue team, so that they can exchange messages and send commands. We will investigate how many UAVs are needed to keep connection among members, and how to adjust their locations as members move. Also, locations of UAVs affect the bandwidth of network channels, when a pair of members are using voice or video chatting, good quality of channels connecting them should be guaranteed.

IV. Social Impact on Humanity or Local Community

After a disaster happens, to make disaster relief and rescue activities conduct in a fast and highly efficient manner, the provision of essential information concerning the disaster area situation is an important pre-requisite. A larger-scale disaster such as a big earthquake, tsunami or hurricane may require rescue activities that are beyond the local government's response capabilities. Besides official rescuers, volunteers and local residents must also react efficiently in a coordinated manner according to the real-time situation. A critical problem that may encounter after the disaster is the unavailability of the Internet. For example, after the Great East Japan Earthquake on March 11, 2011, the Internet in Tohoku district was temporarily shut down for a long time. As a result, only some limited and general information can be obtained through the radio or the TV systems. The lack of specific people-centric information, e.g., demands, supplies and health conditions of individuals, makes the rescue process not efficient enough. When Internet is available, it is not difficult to collect such information by smartphones, which are already quite popular nowadays. Unfortunately, during the Internet unavailability period, none of existing information sharing systems works. These facts motivate us to design an Internet availability resilient information management system as an efficient solution to the above problems. Our RIM system can construct the alternative network and disaster management system which can be very useful after disasters.

V. Implementation Status, Testing and Trial

We have already developed a prototype system. Fig. 6 and Fig. 7 show some snapshots of the DMA application on a smartphone. Fig. 6 (a) shows the top menu for normal users. We can invoke any functions from the menu. To report injured person, "HELP" menu is used and the status and location of the injured person can be easily reported. The menu shown in Fig. 7 (a) is for rescuers and doctors. The triage is supported. By following the smartphone menu, the triage process is finished. All the other functions have already developed in each DMA application. Fig. 8 shows the graphical user interface (GUI) of the RIM server realized in a Linux machine. By clicking an appropriate menu button, the operator can manage the stored data and distribute the information to the users' smartphones or tablets. Currently, we are checking the usability of the system through evaluations and demonstrations.

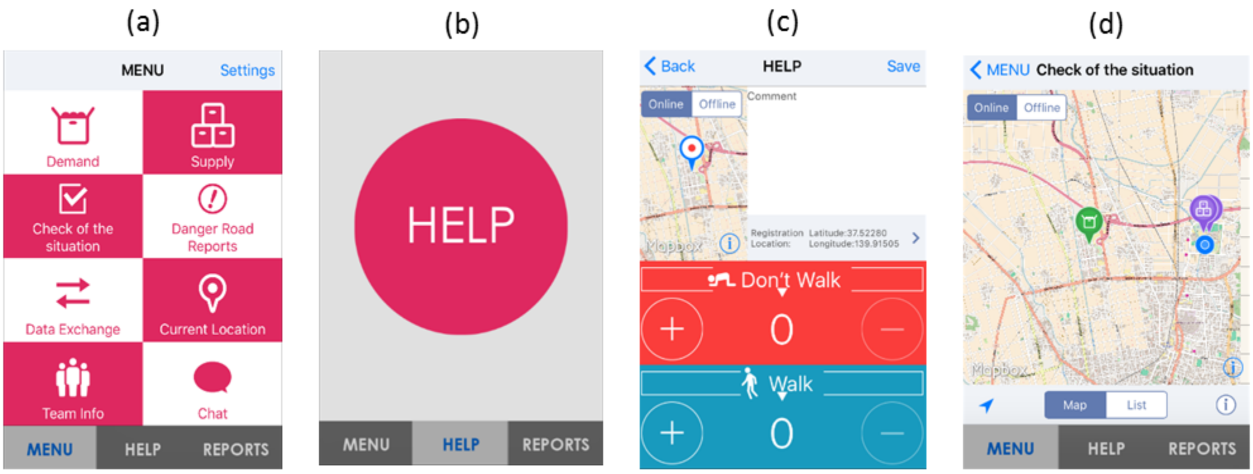

Figure 6. Snapshots of DMA application for normal users

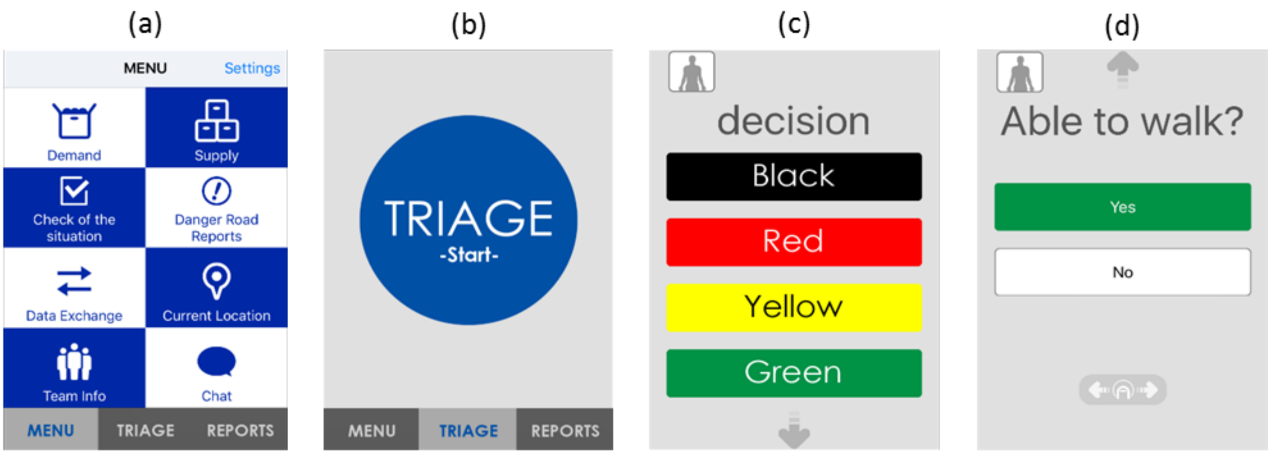

Figure 7. Snapshots of the DMA application for rescuers and doctors

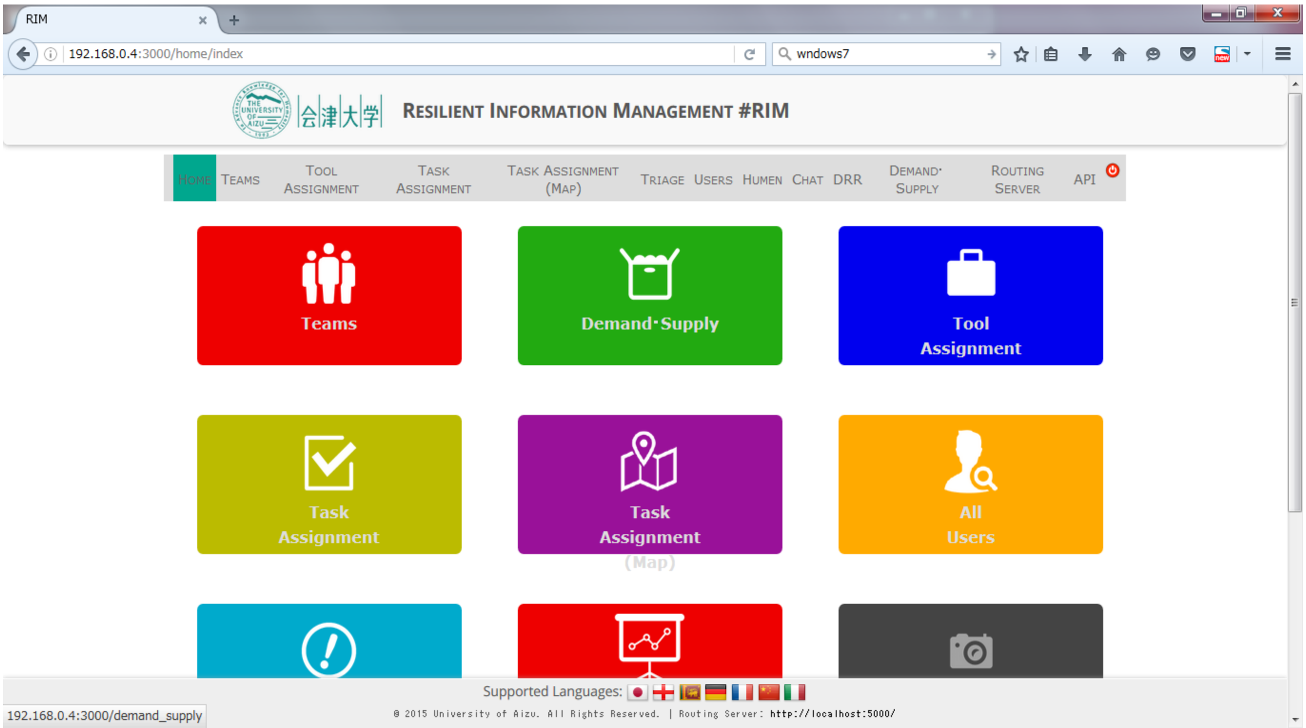

Figure 8. The graphical user interface of the RIM server.

VI. Contact Information

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