# Towards Information Services for Disaster Relief based on Mobile Social Networking

Sander Wozniak and Guenter Schaefer
Telematics and Computer Networks Research Group, Ilmenau University of Technology, Germany

## Abstract

The response to natural and man-made disasters as well as large-scale catastrophes has always been a challenging task. While in the past the focus of existing research has been on designing information and communication technology (ICT) for official decision makers and relief forces, the idea of incorporating the public into response efforts has begun to emerge recently. With more and more people carrying powerful mobile devices (e.g. smartphones), mobile social networking techniques offer new ways of communication, information sharing and response coordination among victims, volunteers and official rescue personnel. Motivated by these new possibilities, within the scope of this paper, we provide the following contributions. First, based on the process of disaster management, we identify several information services, which should be considered when designing new technologies for disaster response, and provide a systematic description and discussion of these services. Second, we discuss a variety of technical requirements and present a communication architecture for these information services. Finally, we outline related work and discuss future research directions.

## 1 Changes in Disaster Response

With local communities usually being unable to effectively respond to natural disasters and large-scale catastrophes (e.g. floods, earthquakes, cyclonic storms, tornadoes, wildfires), technological disasters (e.g. structural fires, dam failures, hazardous materials incidents, nuclear accidents), as well as events motivated by social conflict (e.g. riots, wars, terrorism, CBRN incidents) beyond the scope of day-to-day emergencies, federal and international relief efforts require complex coordination and disaster management techniques [1]. While emergency management traditionally considers the four phases of mitigation, preparedness, response and recovery, a focus of research in terms of information and communication technology (ICT) is usually on disaster response, i.e. the challenge of improving the immediate post-incident relief efforts by enabling communication and supporting information exchange among official rescue personnel. Although the adequate response to a disaster, i.e. the management of operations, planning and logistics, is vital for saving as many human lives as possible, due to the extent of the damage and the limited amount of rescue personnel, official authorities are often unable to provide instant help to all victims [2,3]. Even under the assumption that major parts of the communication infrastructure may still be functional or can be restored quickly, decisions still have to be made without proper knowledge of the actual circumstances, as only the feedback and reports of official first responders is able to increase the situational awareness of decision makers.

Based on the above-mentioned observations and the fact that the affected population is usually the first to witness and respond to an incident, the vision of *public participation* via mobile social networking techniques has begun to emerge as a promising new field of research recently [2-5]. This vision is motivated by the fact that more and more people are getting familiar with online social networks and web-based services and are using them actively. Furthermore, an increasing number of people are in possession of mobile communication devices like smartphones. These devices are equipped with sensitive microphones, high-resolution cameras, GPS receivers, motion and acceleration sensors, as well as multitasking operating systems running on increasingly powerful batteries, processors, memory and graphics processing units yielding a performance comparable to five to ten year old desktop PCs. With the success of these devices, mobile social networking applications, where users are able to share information via a smartphone connected to a web-based service, have emerged rapidly. Thus, on the one hand, the short-term goal is to employ existing online social networks, microblogging and other web-based services as a fast and less hierarchical way of gathering and sharing information among officials and voluntary first informers (*citizen journalists*), as well as among victims (*citizen-to-citizen communication*) [2,3]. On the other hand, the long-term vision is to develop and establish new innovative information and communication technolo-

gies for disaster response to further enhance official and voluntary public relief efforts beyond the scope of retrieving and extracting information from existing online social media sites.
Therefore, within the scope of this paper, we make the following contributions. First, we discuss information needs for several audiences in a disaster situation. Second, we identify several information services for disaster response and provide a comprehensive description and motivation of these services. Furthermore, we present technical requirements, as well as a communication architecture for the implementation of these services. Finally, we outline related work and discuss future research directions.

# 2 Information Needs

In a disaster scenario, there are typically two groups of different or partially overlapping information needs: *official responders* and the *affected population* residing in the area of the incident. Between and within these two audiences, several one- or two-way information pathways can be identified [2]: among officials, among the population, as well as between officials and the population. In the following, the information needs of both groups are described in more detail.

## 2.1 Official Responders

In order to be able to organize response efforts effectively, federal agencies (e.g. the United States Federal Emergency Management Agency, FEMA), as well as inter-governmental and non-governmental organizations (e.g. the United Nations Office for the Coordination of Humanitarian Affairs and the International Red Cross) have to be able to communicate with each other at the site of the incident (e.g. via email, voice communication, multimedia streaming or web-based communication platforms) [1].
Furthermore, in order to be able to develop an incident action plan, i.e. in order to define mission objectives and response measures, relief forces have to obtain knowledge of the current circumstances (*situational awareness*) [1]. Such information might be the current whereabouts of victims, the location and assignment status of resources like rescue personnel and vehicles, information about the local infrastructure, e.g. operational airports, capacity of road infrastructure, hospitals and shelter locations. In addition, relief organizations have to obtain reports about the extent and severity of damages and potentially remaining and evolving hazards. For decision makers, it is important to obtain this information as soon as possible in a timely and accurate manner in order to be able to develop an adequate incident action plan.

## 2.2 Affected Population

Regarding the population affected by the disaster, one of the most important aspects is typically to obtain medical treatment, food, water and shelter. However, with the communication infrastructure being overloaded, damaged, or inoperable due to power outages, victims are often unable to call for help and receive assistance within the first critical 72 hours. Hence, in order to obtain medical treatment, victims may try to reach hospitals or shelters in their surroundings. However, with some shelter buildings and hospitals being destroyed or unreachable due to road infrastructure obstructions, information about the extent of the damage, remaining operable roads and the location of useful resources (e.g. hospitals, gas stations, food and supply of clean water) may be essential for victims to reach a relief camp or to hold on until official response forces arrive. Furthermore, when moving inside the area of the incident, victims should be informed about potential hazards along their desired route or alerted when approaching a certain danger.
In addition, while certain injuries may render victims helpless and therefore require the intervention of relief forces, other parts of the affected population may still be able and willing to provide aid and support to others [2,3]. Hence, for these volunteers or *public responders*, it is important to obtain knowledge about the location of injured or handicapped victims, which are in need of assistance, as well as the position of the nearest suitable treatment centre or hospital.
Finally, with friends and families being separated in the course of an evacuation or the incident itself, reuniting individuals may be an important aspect to minimize psychological stress or trauma among the affected population. Apart from reuniting individuals within the area of the incident, acquaintances that are not affected by the incident are also interested in the condition and whereabouts of friends, family members or employees, which might have been a victim of the incident. Therefore, individuals should be able to get into contact with acquaintances inside and outside the affected region.

# 3 Information Services

This section describes the most basic information services that might be fulfilled by ICT for disaster response based on mobile social networking. The goal of this overview of potential information services is to enable a systematic analysis and easier comparability of systems and architectures.
In order to identify information services for disaster response, we consider the basic steps of disaster management. This iterative process can roughly be described by the following four phases, which are derived from FEMA's National Incident Management System (NIMS). It should be noted here that these


**Figure 1:** Iterative Disaster Management Process

phases also concern public response efforts, where decision makers are volunteers among the population.

1. *Situation Assessment:* In this phase, decision makers try to obtain awareness for the current circumstances at the site of the incident. This usually involves retrieving information about damages, potential hazards, the location and status of victims and wounded, as well as requests for needed resources (e.g. supply or additional personnel).

2. *Resource Reviewing:* Given the current situation, decision makers review the resources, which are available for potential response actions. Resources may be, for example, available personnel, vehicles or bed capacities of medical treatment centres.

3. *Action Planning:* Based on the assessment of the situation, as well as considerations regarding the available resources, decision makers develop an incident action plan describing several actions and tasks to be fulfilled using well-defined resources.

4. *Plan Execution:* Finally, in the last phase, the corresponding tasks of the incident action plan are executed. Here, it is important for decision makers to retrieve reports about the progress of the tasks to get feedback on the actual fulfilment of the action plan.

Based on this management structure, we now identify and discuss several basic information services. Figure 1 gives an overview of the services derived from the above-mentioned four management phases.

## 3.1 Damage Assessment

The damage assessment service provides a registry and description of rather static damages dealt by the disaster (e.g. damages to hospitals, shelter buildings and transportation infrastructure) to official responders or the affected population. Damage information may be reported by for example official first responders or the affected population. The description of damages should be machine-readable to enable automatic visualization and processing.
*Official responders:* This service might be implemented using a centralized or distributed database, which is provided and administrated by an official agency or organization. Assuming that the update frequency of the damage data repository is rather small (apart from an initial queue of arriving reports), the database should be optimized for a high number of queries and efficient reading.
*Affected population:* Due to the lack of a centralized storage structure, in order to implement this service for the affected population, a distributed database structure has to be established in an ad-hoc manner on the mobile devices of the population. A possibility may be, for example, to use the memory of smartphones and rely on distributed hash-tables maintained over a wireless ad-hoc network among the mobile devices to store and retrieve damage descriptions.

## 3.2 Hazard Monitoring

The hazard monitoring service provides an overview of currently existing or potentially evolving hazards in the post-incident area. Therefore, the hazards should be monitored in real-time to enable forecasts of dangerous developments. The description of a hazard

should also be machine-readable and include information about the vulnerability of the affected region to enable automatic risk assessment, decision of intervention, and prioritization of relief actions.
*Official responders:* This service may be implemented using a centralized database system. Furthermore, a realization of this service should be able to issue warnings and alerts.
*Affected population:* People in the affected area are usually only interested in hazards, which might affect them (i.e. in their close surroundings). Such a warning system may be implemented in a distributed manner using a geocast approach, which aims at delivering messages to certain geographical regions similar to virtual warning sign approaches in the field of VANETs [6]. Nevertheless, in terms of the navigation service, individuals may also be interested to obtain hazard information reports along a planned route. Hence, this service should also provide distributed storage similar to the damage assessment service.

## 3.3 Victim Registry

The victim registry service provides a list of people assumed to have been residing in the area of the incident. Furthermore, this service should allow retrieving status information about victims (last known location, missing/dead/treatment) and provide patient tracking (health condition, treatment location). The information about victims should be machine-readable and compatible to existing hospital management systems.
*Official responders:* This service may be implemented according to the damage assessment / hazard monitoring services using a centralised database system.
*Affected population:* In order to provide public (and official) responders with information about victims in distress, the victim registry service might be implemented similar to the hazard monitoring service by delivering a list of the victims to the corresponding geographic region.

## 3.4 Need Registry

The need registry service is used to keep track of needs and resource requests from response teams, other relief organizations or public responders from the affected population. Information about needs and requests should be machine-readable to enable automatic analysis, prioritization and mediation of available resources (e.g. in order to provide suggestions to decision makers).
*Official responders:* This service may be realized using a centralized database system.
*Affected population:* According the above-mentioned services, this service might be implemented using a mobile device / smartphone storage system.

## 3.5 Resource Inventory

The resource inventory service enables users to locate, monitors and tracks the status (e.g. assignment) of resources like for example personnel, vehicles, fuel, food and water, medical supplies, shelters or hospitals (current bed capacities). The description of resources should be machine-readable, e.g. in order to to enable matching of requests and available resources.
*Official responders:* This service might be implemented using a centralized database system according to the services mentioned above.
*Affected population:* In order to track or locate resources in the vicinity of a public responder or victim, the previously mentioned smartphone-based storage system might be employed here as well.

## 3.6 Task Monitoring

The task monitoring service provides an overview of the current progress of certain tasks, which are part of an incident action plan. Tasks should be described in a machine-readable manner to enable automated tracking of the fulfilment of certain tasks.
*Official responders:* According to the services described above, this service might be implemented using a centralized database system.
*Affected population:* In contrast to the hierarchical structure of an official emergency management system, the monitoring of services among volunteers requires a more sophisticated, distributed tracking mechanism. Since volunteers among the affected population are not bound to a command structure to fulfil the assigned tasks, their actions have to be monitored more closely in order to detect deviations (e.g. using plausibility checks on their movements) and thus enable the reassignment of tasks.

## 3.7 Information Dissemination

The information dissemination service is used to announce official or unconfirmed information, warnings or alerts to the affected population. While traditionally, this service has been implemented using broadcast services like for example scoreboards, radio or television, a more sophisticated implementation might consider disseminating information only to specific regions or individuals among the population.
*Official responders:* This service might be realized via cell broadcasts or in terms of a wireless ad-hoc network of mobile devices using existing multicast approaches like for example geocast.
*Affected population:* Since individuals are not able to announce information via cell broadcasts, only multicast techniques may be applicable for implementing this service among citizens in the area of the incident.

## 3.8 Event/Need Reporting

The event and need reporting service enables official first responders and the affected population to report observations about certain events (e.g. emergencies, damages and hazards), as well as needs and status information (e.g. requests for food, water or medical supply, emergency calls and "I'm OK" notifications) to other information services (damage assessment, hazard monitoring, victim / need registry). The description of these needs and events should therefore be machine-readable and employ an exchange format, which is compatible to these services.
*Official responders:* In order to implement this service, a communication stack like TCP/IP may be used to send messages over a remaining wired or wireless network to servers provided by relief organizations. However, due to the potentially high number of reports, a more complex, distributed solution may be necessary to process the arriving information.
*Affected population:* While individuals may be able to report needs and events using TCP/IP over a wired infrastructure like the Internet, this service should also consider using a wireless ad-hoc network and delay-tolerant routing schemes to collect, aggregate and distribute information about needs and reports inside a network of mobile devices.

## 3.9 Expert Consultation

The expert consultation service enables users to identify and locate experts among the affected population. This enables for example decision makers to guide professionals to certain regions requiring assistance or to obtain a remote analysis of a situation by establishing a communication link between the user and a suitable expert (e.g. trained in medical treatment or hazardous materials) and providing information about the situation, e.g. by sending a photo to the expert.
*Official responders / Affected population:* While flooding a query for experts inside the network at the disaster site may be able to identify trained personnel among the affected population, more sophisticated approaches might employ distributed registries of experts inside specific geographic regions, enabling a more efficient localization of certain individuals.

## 3.10 Navigation

The navigation service enables route planning and guidance to certain locations inside the area of the incident. This is useful for official and public first responders, as well as victims to reach certain destinations like for example relief camps and hospitals. Apart from basic route planning, this service should consider a more sophisticated approach, which aims at incorporating information about traffic conditions, damaged road infrastructure, avoiding hazardous areas and considering resource capacities of hospitals to guide users to the most suitable location.
*Official responders:* In order to implement such a navigation service including intelligent route planning, information from other services (e.g. damage assessment and hazards monitoring) may be accessed. Therefore, for decision makers, the realization of this service is straightforward. However, when providing navigation to personnel deployed in the disaster area, accessing a centralized server may be not efficient. In this case, an implementation should consider a peer-to-peer system for sharing traffic information over a fixed or wireless infrastructure.
*Affected population:* Since accessing a central server may already be too expensive for official responders, a realization of this service for public responders and victims might rely on accessing information stored on mobile devices by querying the geographic regions along the shortest route and iteratively adapting to a more suitable route.

## 3.11 Request/Pledge Mediation

The request and pledge mediation service is used to match requests and fulfilment offers. Usually, this only concerns relief efforts among the affected population in order to provide public responders with a tool for self-organised task planning based on the information services of damage assessment, hazard monitoring, as well as victim and need registry (e.g. in order to assign tasks to individuals or small groups). In contrast, among officials, the incident commander or unified command typically performs the task of request and pledge mediation in cooperation with the corresponding section chiefs (e.g. logistics section).
An implementation of this service should provide an overview of relevant incidents in the surrounding area, a list of potential responders and basic communication among these volunteers, e.g. group calls or multi-user chat, which might be realized using a multicast approach over TCP/IP.

## 3.12 Contacting Acquaintances

The service of contacting acquaintances enables users among the affected population to communicate with family, friends or other acquaintances (e.g. in order to report about the location, health condition or a planned evacuation route of an individual to meet at a certain relief camp). A realization of this service has to identify the location of individuals without a centralized register server to handle a potentially high number of requests. With flooding queries to find acquaintances being too expensive, geographic forwarding schemes may be employed to limit and refine searches to the assumed location of an individual.

# 4 Communication Architecture

This section provides an overview of the technical requirements, the communication architecture, as well as a discussion of the shortcomings of current information and communication technologies regarding the design of future ICT for disaster response.

## 4.1 Technical Requirements

Apart from the basic information services, when designing ICT for disaster response, a variety of technical requirements have to be considered.

- ***Robustness:***
  - *Network Partitioning:* Information services should be able to cope with a partitioned network, i.e. they should be disruption- and delay-tolerant. Furthermore, they should be robust against a dynamically changing partitioning of the network.
  - *Node Failures:* In a post-disaster environment, certain parts of the remaining infrastructure, e.g. mobile devices or cell towers, might become inoperable due to the loss of power or damage taken in the course of the incident. Hence, information services should be robust against a certain fraction of node failures within the network.
  - *Node Movement:* With mobile devices being carried by victims trying to reach treatment areas, an information service should be able to support a potentially high degree of node mobility of a certain fraction of nodes.

- ***Availability:*** Information services should be designed to ensure the best possible availability to users, potentially including resistance against Denial-of-Service attacks, for example in catastrophes in politically unstable regions.

- ***Reliability:*** Since certain information (for example a request for help) may be critical to save human lives, its reception at the respective destination (e.g. some volunteers in the surrounding area) in a timely and accurate manner must be ensured with a high probability.

- ***Quality-of-Service:*** Due to limited wireless channel capacity, information flows should be prioritized so that different information services do not interfere with each other. In particular, the wireless channel should not be overloaded in order to be able to deliver important reports and warning messages with a high priority at all times.

- ***Energy Efficiency:*** In order to keep the network infrastructure and thus the information and communication services available as long as possible, algorithms should be tailored to work as energy-efficient as possible.

- ***Scalability:*** With disasters typically affecting a high number of people, information services for victims and volunteers should support a high number of participants and be able to handle a large amount of user generated content (e.g. hazard warnings) by incorporating data aggregation and data fusion techniques.

- ***Self-Organization:*** The communication network should be established automatically and configure itself for operation so that either the existing infrastructure or ad-hoc communication is available. In particular, the network should be able to handle the arrival and departure of nodes.

- ***Localization:*** An important technical requirement of ICT is the ability to automatically obtain the current location of its user as accurately as possible under the given environmental constraints. Information about the current location of a user is normally required for emergency calls or when reporting damages and hazards.

- ***Interoperability:*** Due to the involvement of different governmental agencies and relief organizations working independently (up to a certain degree) in so called clusters [5], the interoperability of data formats has to be considered to enable easy sharing of information among victims, volunteers and rescue personnel.

- ***Security and Privacy:*** In terms of security, user-generated content has to be verified to prevent false damage or hazard reports. This could for example be achieved using majority-voting schemes where information has to be rated by other users in order to increase information credibility.

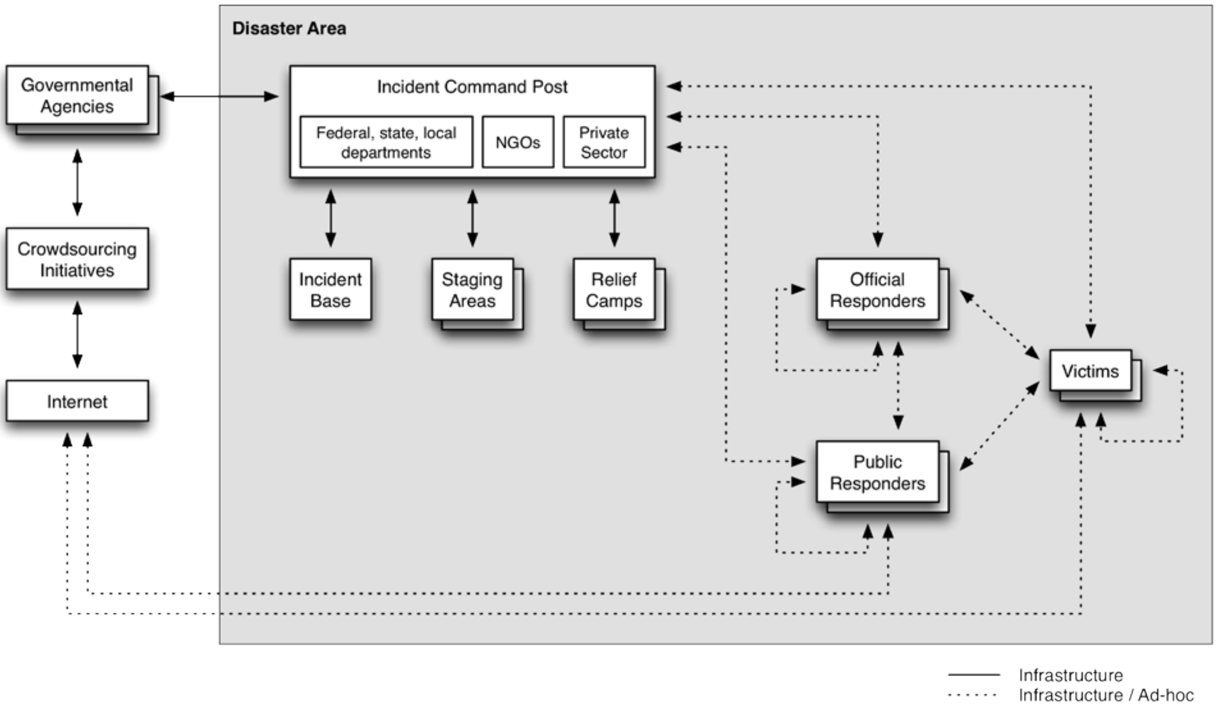


**Figure 2:** Communication Architecture

In addition, privacy concerns should be addressed as well. While, for example, within the disaster area, accessibility to user profile information from online social networks should be extended, anonymising or restricting access to certain information about victims, which could be published for friends of relatives over the Internet, should be considered.

## 4.2 Architecture Overview

When implementing the above-mentioned information services according to the technical requirements, the following communication architecture should be considered (see figure 2).
In a disaster scenario, according to FEMA's National Incident Management System, there are four types of facilities: incident command post, incident base, staging areas and relief camps. Typically, the incident command post is the center of all official response communication. The incident base is established at the location of the primary support activities and provides equipment and personnel. Staging areas are established as a temporary location of resources that await further assignment. Finally, relief camps are established as satellites for the incident base all over the incident area to provide direct support for ongoing response operations. These facilities are usually able to communicate with each other over an infrastructure, which is established by technicians of communications units upon the arrival of relief organizations.
In terms of the affected population (victims and volunteers, i.e. public responders), existing infrastructure may be used for communication. However, in case of malfunctioning infrastructure, the affected population should still be able to establish ad-hoc communication using their mobile devices. These communication links might also only be intermittently connected, motivating the need for delay-tolerant networking in such an environment.
Finally, the affected population may be able to access the Internet sporadically using the remaining infrastructure. In this case, information may be uploaded to social networks or other web-based services. Crowdsourcing initiatives may then try to extract, filter and aggregate useful information from the corresponding services and make this information available to official agencies or the affected population.

## 4.3 Discussion

Existing mobile devices like smartphones, which are widely used today, are currently not able to establish an ad-hoc communication infrastructure. Nevertheless, with mobile social networking applications for every day use becoming more popular, the hardware of future mobile devices might very well be able to establish ad-hoc communication. Furthermore, securing and configuring a communication channel in a self-organised manner is an additional requirement not yet met by current hardware.
Apart from the problem of establishing ad-hoc communications, the issue of overloading the communication infrastructure or the wireless channel after a disaster is still present today. Thus, availability, reliabil-

ity and scalability of communication services have to be considered in the development of future applications to provide an appropriate quality-of-service.

Furthermore, today's mobile devices are unable to provide efficient energy management to maintain an operational network infrastructure over the course of several days (at least 72 hours). In order to implement information services for disaster response, future mobile devices will have to rely on some kind of energy management mode for emergency situations.

In terms of localization, GPS can already be used to obtain the location of a mobile device today. Nevertheless, indoor localization of mobile devices is still an open issue and should be considered in the development of future hardware. Here, using nearby devices as anchor nodes, which are aware of their own location, might be a promising direction.

# 5 Related Work

MEISSNER et al. describe the design challenges, network aspects and basic architecture of an information and communication infrastructure for relief forces [7]. The proposed architecture, however, does not incorporate the possibility of public participation using mobile social networking applications.

Regarding public participation in disaster response, PALEN et al. discuss a basic scheme aimed at integrating and publishing information about an incident from social media websites using information extraction and natural language processing techniques to emergency workers and the affected population via web-based applications and services [2].

ANDERSON et al. present the architecture of a data analytics infrastructure to support future research on the challenge of extracting useful information about a disaster from social media and news websites [8].

In terms of crowdsourcing efforts for disaster relief, several web-based platforms have been developed recently (e.g. *Ushahidi*[1]). While these platforms provide tools to extract and filter useful information from social media websites, SMS or emails to increase situational awareness of rescue personnel, they do not enable communication between officials and citizens, as well as mutual aid and public response efforts among the affected population.

Apart from academic work, several emergency management information systems have been developed in the last few years. Prominent examples are systems like *Sahana*[2], *WebEOC*[3] and *E Team*[4]. While these technologies provide useful tools to relief forces, these systems do not consider applications for public first responders, as well as information services for the affected population.

[1] http://www.ushahidi.com/
[2] http://sahanafoundation.org/
[3] http://www.esi911.com/esi/
[4] http://www nc4.us/

# 6 Conclusions

In this work, we discussed information needs of official responders and the affected population in a disaster scenario. Furthermore, we identified several information services for disaster response and presented technical requirements, as well as a communication architecture for future ICT.

Regarding future work, a basic question in terms of ICT for disaster response is how to establish a robust, delay-tolerant infrastructure in a self-organized manner. While there is research regarding delay-tolerant and pocket switched networking [9], these approaches usually focus on mobile social networking applications and do not consider the specific requirements of information services for disaster response [10,11].

Furthermore, in terms of mobile social networking, the focus of existing research is usually on privacy [12]. Privacy, however, may be less of a concern in a disaster scenario, where it is more important to prevent the injection of malicious user-generated content. In order to filter malicious data, the applicability of secure data aggregation techniques [13] from the area of sensors networks to pocket switched networks for disaster response applications should be investigated. While, for example, trusted nodes are difficult to realize in sensor networks (attackers may tamper with the hardware of the nodes), in pocket switched networks, trusted nodes may be implemented using asymmetric public-key cryptography with official certificates distributed by a government before the emergency.

Finally, another open issue is the lack of realistic mobility models for disaster scenarios, which are necessary for evaluating the performance of information services [14-16]. While it may be difficult or impossible to develop one single model for all potential incidents, mobility models should aim at supporting specific disasters, incorporating mobility of both official response forces and the affected population. Nevertheless, when developing a disaster mobility model, a fundamental problem might be the validation with real-world movement traces.

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