# Challenges in Information Systems for Disaster Recovery and Response

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*Abstract. Disaster recovery and response require a timely coordination of the emergency services. IT-technology provides a tremendous potential to increase efficiency and effectiveness in this area by propagating information efficiently to all the right locations. In this paper we sketch requirements and describe challenges for an integrated disaster management communication and information system, addressing in particular networking, configuration, scheduling and data management issues.*

## 1 Introduction

Dealing with disasters such as earthquakes, floods, to name just a few, poses an ever-present challenge to public emergency services. Their success and efficiency depends on a few aspects: up-to-date information being propagated up and downstream efficiently, effective resource management, and a well-organized cooperation and coordination between the different services.

Up-to-date information needs to be available in real-time for the decisions makers. An integrated communication and information system for easy plug-in into other systems will establish a disaster platform for the reliable and secure exchange and processing of information.

In this paper, we sketch a system that allows for horizontal and vertical information flow from the staff on the scene up to central operations by way of a multi-level wireless voice and data communication infrastructure, as well as integrated applications. By combining network solutions such as trunked radio or satellite technology, wireless LAN ad-hoc networks, and personal or body area networks we will provide at all levels for recording and analysis of the current situation, semi-automatic data aggregation and de-aggregation, resource scheduling, as well as access to services and information sources and sinks.

Usually information systems for disaster response are divided into three phases: the pre-phase addressing the preparations before, the post-phase analyzing what happened during the disaster (lessons learnt e.g. for training) and the phase in between, i.e. the situation during the emergency, our main focus.

The structure of this paper is as follows: Following this introduction, we provide a brief user requirements' analysis and, in section 3, an architecture outline. Section 4 addresses applications and information flow. section 5 discusses (auto-)configuration. Sections 6 address data management issues, respectively. Section 9 concludes this paper.

## 2 User Requirements Analysis

The Fraunhofer Gesellschaft conducted a major study on disaster and emergency management systems [N]. Apart from communication and information management, the following areas were addressed: optimization and simulation, decision support, visualization, geographical information systems, and simulation and training. One of the findings was that maintaining communications is the "primary challenge" during a disaster and that the following major requirements were not yet met in a satisfactory way:

- Integration and linking of information
- Availability of communication, redundancy of links
- Fast data access
- Timeliness and updating of information
- Standardization of information

We refer to the MESA project [M] for requirements in the area of mobile communication standardization.

## 3 System Architecture

A high-level view of the proposed system's communication architecture is provided in Figure 1. The different emergency services' headquarter buildings are connected to each other and government authorities, e.g. the state governor or FEMA, by terrestrial and/or satellite networks. Likewise, when disaster site command posts are established, they are connected by terrestrial wireless or satellite links to the respective HQs. For "hot spot" on-site communications, a wireless LAN (infrastructure, ad hoc, or both) is set up. Firefighters and other emergency personnel may be equipped with personal or body area networks, providing connectivity for sensors and terminal displays, thus acting as both data sources and sinks.

The information flow of applications can be both horizontal, i.e. between peer entities, and vertical, i.e. along an organization's hierarchy and beyond; both push and pull information propagation are supported.

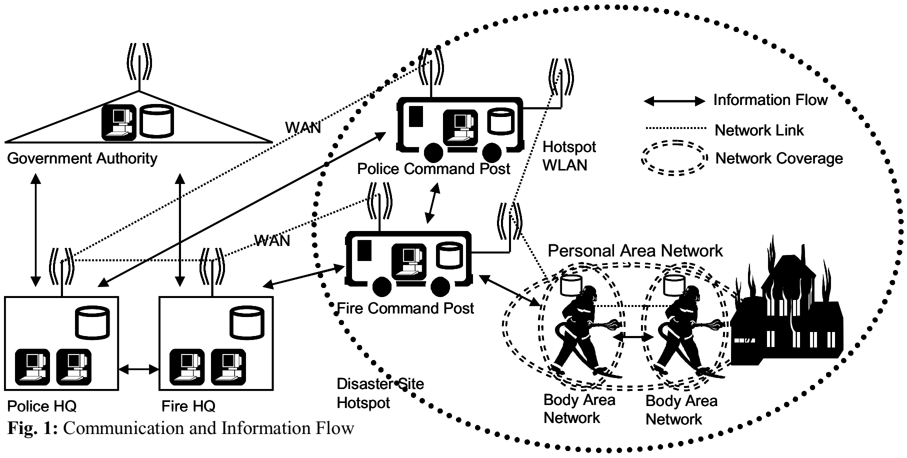


**Fig. 1:** Communication and Information Flow

## 4 Applications and Information Flow

In this section, we take a bottom-up approach and first describe how frontline personnel like firefighters or other rescue workers operating in difficult terrain may benefit from the proposed system. Firefighters' equipment often includes sensors and detectors, e.g. for radiation or explosive gases. The readings are traditionally transmitted by voice communications to squad leaders. More immediate and reliable data transmission can be accomplished using smart sensors linked, via networks, to a computer in the squad leader's vehicle, where they are immediately analyzed and put into context. In some cases, data may be coupled to the location of the measurement using portable GPS receivers, so, for example, danger zones can be determined more precisely. Moreover, vital parameters of the emergency personnel can be transmitted continuously for monitoring purposes [M]. Thus firefighters are data sources in our system, but they are also data sinks: Messages, hazmat warnings, maps, even data on missing persons may be transmitted to their robust mobile devices. Of course, offline operation capability is a must in a difficult communication environment.

The hierarchy levels of all organizations involved in a rescue effort need to interact closely. They correspond to aggregation levels at which gathered data is analyzed, put into context, and transformed into reports (upstream) and instructions (downstream). At the same time, decisions often have to be taken in an ad hoc manner, which requires efficient access to current information, or, in some cases, an online "help desk". Our proposed applications allow the data to be correlated with other information, to be aggregated or de-aggregated, and to be exchanged with others according to an information flow model deemed appropriate for the situation. A workflow system using templates and taking the involved organizations and the number of hierarchy levels into account, easily adapts to changing organizational structures and facilitates collaborative work within and across services.

Headquarter staff is often responsible for scheduling and coordination and acts as an interface to other agencies and the public. They are, due to their physical distance to the disaster site, particularly dependent on the up-to-date information inflow. On the other hand, HQs usually have vast amounts of stored data, e.g. on hazardous materials, which may need to be accessed by on-site personnel. This calls for integrated applications building on wide area data links between the HQs and site command posts. If a disaster spreads, even HQs may need to be relocated, or operations directors may decide to move closer to the scene, so it is vital to provide a "portable information environment" ready for relocation. This places additional requirements on databases and cooperative environments provided for HQs.

## 5 Configuration

We have so far argued that the proposed system has to be able to manage vast amounts of data at all levels. Exchanging data in real time between the right entities is a key challenge. The information flow must be controlled in such a way that during the disaster the system is robust and ready to be extended or (re)configured easily. This section shows that these requirements call for auto- and self-configuration of the services in the network.

### 5.1 Motivation for Auto-Configuration

Without the proper configuration of hosts in networks, they will not be able to find or communicate with each other. Device configuration is therefore of utmost importance. This can be done either statically or dynamically. Devices connected permanently to an administered network are usually assigned static network configuration parameters [HK]. Not permanently connected devices can use dynamic network configurations. The devices themselves must be configured, i.e. all the necessary parameters must be assigned to the host (device) by a network configuration service. The network configuration service itself also requires configuration. However, in a communication and information system aimed at disaster recovery, manual administration of network hosts is impractical or impossible. Hence, automatic configuration of the hosts is desirable.

### 5.2 Communication Spheres

As previously suggested, there are three kinds of actors in the system with regard to their degree of mobility:

- Stationary actors: Police, fire, etc. HQs, government authorities, and even foreign authorities or organizations (in case of disasters affecting several countries)
- Semi-mobile actors: mobile command posts.
- Mobile actors: frontline personnel, e.g. firefighters.

The communication can be seen as a "network in network" hierarchy as well. The mobile actors may have several sensors communicating with a handheld device. In essence, these gadgets form a small wearable, or body area, network. The communication to the nearest mobile actors can occur in a personal area network.

As discussed in section 4, the disaster site is covered by a WLAN, operated by semi-mobile actors, who, in turn, can communicate with stationary actors through a WAN.

### 5.3 Configuration of Devices

One aspect of the configuration of mobile devices is addressing parameters. Data sinks as well as data sources must know with whom to communicate, i.e. the device interface must be configured with a unique address. Duplicate address assignments must be detected, and message collisions must be managed.

Typically, a mobile actor will operate (either manually or automatically) sensor devices, which gather different types of data. Some data, like the amount of explosive gases in the air, is relevant both for him personally as well as for the command post. Other data, such as positioning information is not crucial for the mobile actor, but rather for his superiors at the command post.

Similarly, the mobile actor may want to access a mapping catalogue at his own and/or another command post. Or, he may want to obtain readouts of the vital parameters of a fellow mobile actor. This scenario repeats itself throughout the whole hierarchy depicted above. In essence, there will be a large number of services available offering different kinds of information or connection possibilities.

### 5.4 Discovery of Services

The discovery of these services can be managed in various ways. At the top hierarchy layers (stationary and semi-mobile actors), the service information management can be regulated using a stationary service trader. Actors offering services could register them in the service trader, as well as poll it for available services.

For the mobile actors, a dynamic process for starting and operating a (mobile) service trader is an option. To cope with the extremely dynamic situation, services listed in this mobile service trader have a significantly lower registration lifetime, in order to correctly depict the network state. Alternatively, if the number of mobile actors currently in contact is beneath a certain threshold value, no service trader will be assigned at all. In this case, service information can be managed and exchanged through the use of multicast.

As sensor devices are turned on and off and different actors come in and out of reach of each other, the list of available services for each individual actor will most probably be changing constantly. This fact, in conjunction with the amount of diverse information services involved, suggests a system that *dynamically* and *automatically* configures itself. I.e. the devices must on a stand-alone basis find out which services are available, which other actor to send its readings to, present and describe its own services to other devices in the vicinity, and so on. As much as possible of the configuration and managing of services must be automated to facilitate the tasks of the various actors. The goal is to present the right data to the right actor at the right time with as little human intervention as possible.

Moreover, an autoconfiguration-enabled system can also manage the load on the network, e.g. through directing traffic to alternative command posts. In this manner, communication "bottlenecks" can be avoided, which otherwise could prove fatal if occurring at the wrong time. We will come back to this issue in sections 6 and 7.

## 6 Data Management

Distributed applications for disaster management have to deal with unreliable communication environments, low data transmission rates, and different processing and storage capabilities of the devices used. Hence good communication quality cannot be guaranteed. On the other hand, decisions in the command posts are based on information received from people working in the critical area. Vice versa, people in such areas act on instructions given by the headquarters. For both sides it is hence important to get complete information, as incomplete information delivery can result in wrong decisions or actions. Furthermore, decisions have to be made quickly. This means that information and instructions have to be delivered fast. Thus, as outlined in the following subsection, the main challenges for data management in mobile and unreliable environments, especially in disaster situations, are reliability and performance.

### 6.1 Challenges

*Reliability* means that the user always receives complete information of the highest possible timeliness. Incomplete information has to be detected and, if possible, must be requested again. Otherwise the application or user has to be notified about the transmission failure. In less critical situations it might be possible to reuse information from previous transmissions.

The second important factor is the *performance* of the system. Beside the application, the response time of the system depends on the bandwidth of the communication channel. Hence low transmission rates make it difficult to deliver e.g. complex maps within short time. The data management has to guarantee the efficient usage of the communication channels. Moreover, the response time of the system should be largely independent of the number of communication partners in the system.

Furthermore, the data structures used for data exchange must be flexible in different ways. Sensors can provide their data in proprietary formats. Hence they have to be transformed at some point to the standard data structure. This can be done at the receiving device or, if the device is not able to do this, the data has to be encapsulated into a standard message and transformed at some other point. In addition, the compatibility of different versions of data schemas has to be handled. Data schemas can change over time if new versions of an application are developed, but it is important that devices with different application versions still be able to communicate.

### 6.2 Suggested Approach

To overcome the previously identified problem, XML [X] should be used as a standard data interchange format. XML documents can contain all required information – from simple messages to complex maps. Furthermore it is flexible in the handling of evolving data structures. A disadvantage of XML might be long tag names and white space, increasing the document size. But the intelligent selection of tag names in the design phase and compression will reduce the document size significantly.

The efficient usage of communication channels is based on a continuous and balanced transmission of data to avoid communication peaks. Hence intelligent caching, pre-fetching and selection of XML documents are the core technology for the implementation of mobile data management. Caching allows for effective usage of communication bandwidth by avoiding retransmission of mostly static information. Intelligent pre-fetching and selection strategies are used for timely delivery of complex location aware information, e.g. maps of buildings.

The reliability of the system is increased by redundant storage of XML documents on different devices (peers) [G]. Hence information has to be replicated in a peer-to-peer manner among nearby devices. This decreases the probability of information loss in the case of a communication failure because other devices can be used as an "information router". Vice versa, in this way it is possible to avoid the loss of important sensor information.

For the proposed technologies data integrity and timeliness of information are important. A distributed transaction management, which is adapted to the special needs in disaster management, ensures that instructions or technical descriptions are completely transmitted to the receiver. Notifications of incomplete transmissions are necessary. The caching strategy has to take the timeliness level of information into account, e.g. static maps have to be updated less frequently than instructions.

## 7 Conclusion

We have sketched an integrated communication and information system for disaster recovery and response, addressing in particular networking, configuration, data management, and resource scheduling.

In order to make our vision become reality, several IT research disciplines need to work together to realize an effective, yet easy-to-use system that helps emergency services cope with disasters. To name only a few, networking needs to provide robust communications at WAN, LAN, PAN, and BAN levels, integrating heterogeneous networks to allow the rescue effort to proceed smoothly even in the most difficult communication environments. Data management must provide static and dynamic data where and when it is needed. Security is of foremost concern, necessitating solutions for authentification, encryption, data integrity, and non-repudiation. Devices and user interfaces must be tailored to hostile environments and to users who are often not computer literate. Application and information flow designers need to consider fast-changing working environments and resource management is a challenge given the chaotic nature of disasters.

We believe that the IT research community is obliged to respond to the need for technology to support a more informed and coordinated disaster response, and we are convinced that a system such as the one sketched in this position paper would be quite beneficial in this respect.

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