

Mobile Computing in Urban Emergency Situations: Improving the Support to Firefighters in the Field

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Abstract

Communication support is a serious limitation for Latin American firefighters when they deal with emergency situations. The insufficient number of radio channels and the impossibility to deliver digital information force firemen to improvise during response processes, e.g., to make decisions using their experience and poor or null supporting information. These improvised actions affect the time required to take control of an emergency, and also affect the evolution of the crisis situation. Provided most of Latin American fire companies are volunteer organizations, communication solutions that could help to overcome these problems are usually expensive for them. This article presents a low-cost mobile collaborative application, which may be used in emergency situations to overcome most of the firefighters' communication problems. The application, named MobileMap, is the result of the research and development work conducted by the authors, supported by a Chilean fire company, during the last three years. MobileMap allows ad hoc communication, decisions support and collaboration among firefighters in the field using mobile devices. This solution complements the radio communication systems. Since the interactions supported by MobileMap are recorded, it is possible to analyze such information after the crisis and learn for future emergencies. The tool was evaluated in simulated and real scenarios, and the obtained results are highly encouraging.

Keywords: Mobile Collaborative Application, Communication Support, Emergency Support, Decision Support System, Mobile Computing.

1 Introduction

Firefighters are typically volunteers in many Latin American countries. This means they do not receive a salary for their job, and they have minimal support from governmental agencies. Typically, firemen have a regular life and job; however they are able to attend an emergency situation when it is required. Most firefighters carry a radio receiver/transmitter with them to receive a call to participate in emergency relief operations.

A special firefighting unit is in charge of delivering the alarms, assigning resources to an emergency situation and coordinating the response efforts. This unit is known as alarms center, emergency management center or command center. In large cities, each command center typically coordinates the activities of 10-15 fire companies. Each company has headquarters and between two and four fire trucks. Usually, the firefighting community, composed of a command center and its depending fire companies, counts on two or three radio channels to coordinate all the emergency response efforts.

In urban areas, the number of simultaneous emergencies, which need to be coordinated by the command center, could widely vary. In the case of Santiago (Chile), a city with a population of 6 million, there are seven command centers distributed throughout the city. Each command center has to coordinate up to 5 simultaneous emergency situations. Examples of urban emergencies are fires, car accidents, gas leakages, collapses, and chemical/water spills.

Although the radio-based communication used by these units has brought several benefits, it currently represents a limitation for the emergency response processes; particularly in urban areas (Turoff, 2002; Carver & Turoff, 2007; Schöning, Rohs, Krüger, & Stasch, 2009). Taking control of an urban emergency requires to count on quick and accurate information about: (1) the dangers of the situation (e.g. type, size, and evolution/propagation forecast), (2) the affected resources (e.g. building blueprints, electrical/gas networks, access/exit routes or safe places), (3) the emergency location (i.e. the exact address) and the surrounding key resources to inspect (e.g. schools, chemical industries, elderly-care houses) and to use (e.g. hydrants or hospitals); and (4) the status of the response process (e.g.

number and type of assigned fire trucks/firefighters, availability of specialized personnel, police support, and health support). All this information is usually relevant to organize and coordinate the response process; however an important part of it involves digital representations (e.g. photos, blueprints, sketches, or maps), and therefore it cannot be delivered through a radio system or shared in an easy way. This limitation of radio systems has been widely recognized by the research community (Kean et al., 2004; Aldunate, Ochoa, Pena-Mora, & Nussbaum, 2006; Ochoa, Neyem, Pino, & Borges, 2007; Carver & Turoff, 2007).

A second problem with radio systems in urban emergencies is the insufficient number of channels available to support the response processes. This shortage becomes evident when a command center has to coordinate more than three simultaneous emergencies.

Typically the command center has a radio system able to send/receive voice communication in a 30 km radius. Radio systems in fire trucks and portable radio devices are able to transmit/receive voice communication in an area of 2-4 km around them, depending on the equipment broadcasting power.

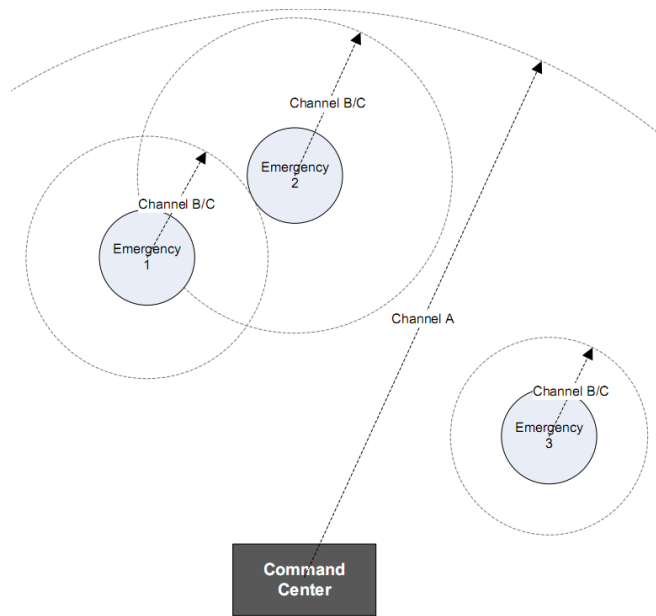


Fig. 1. Urban emergency communication scenario.

Usually, channel “A” (or main) is used to support communication between the command center and each firefighter chief in the field (one incident commander per emergency). If three emergencies are happening simultaneously (Fig. 1), all of them have to share such channel. The concurrency for accessing the channel typically delays information sending/receiving. This delay may occur because e.g., the channel is busy, the message was overwritten by another message sent with a more powerful radio device, or the message is not understandable because it was mixed with another one. These delays to send/receive information sometimes force incident commanders (and also other firemen in the field) to improvise their response actions, because they are not able to wait for additional information or for the channel to become available.

In each emergency situation, there are (in the best case) two additional radio channels available to support the firemen’s activities in the field: channels “B” and “C” (Fig. 1). Channel “B” is used for inter-company communication and channel “C” is for communication within a firefighting company attending an emergency.

When two simultaneous crisis situations are in the same communication range (e.g. emergencies 1 and 2 in Fig. 1), both response processes compete for these channels. Typically, messages delivered by devices with high broadcasting power (in our case, those used in emergency 2) overwrite any other message distributed by the channel during the same time interval (Manoj, & Baker, 2007; Mendonça, Jefferson, & Harrald, 2007). In this case, one of these groups is forced to improvise because is not able to send/receive information with the urgency required by the situation.

The use of the “B” and “C” channels is a bit chaotic (even if the communication range does not overlap) because each radio-transmitter is able to send/receive messages, and most firefighters have one of these devices. Although firefighters have a protocol to use these channels, urgent events typically push firemen to break these rules, and after that the communication becomes very hard to control. In addition, since messages do not have priority, important messages (e.g., an alarm indicating the possible collapse of a building during a fire) cannot be delivered or may fail to be received by first responders due to this overload in the radio channels (Canós, Borges, & Alonso, 2005; Manoj, & Baker, 2007). For these reasons, most firemen have to improvise their response activities (Aldunate, Ochoa, Pena-Mora, & Nussbaum, 2006; Mendonça, 2007).

This paper presents a mobile collaborative tool, named MobileMap, that complements the current radio systems in order to help overcome most of these limitations. For example, this tool also helps fire trucks to arrive quickly to the

emergency site, firemen to retrieve information about the threat and the affected area while they are traveling to the emergency site, and the firefighting organization to record/collect information about the response process, which can be used to learn for future situations.

Ideally, MobileMap runs on hand-held devices which are able to work both as PDA (Personal Digital Assistants) and cellular phones. This is because the system alternatively uses Wi-Fi and GSM networks. However, the tool also runs on laptops, netbooks and several types of cellular phones with or without Wi-Fi communication support. In fact, the functionality available to the user will depend on the features of the computing device.

The next section briefly explains the emergency response process. Section 3 presents related work. Sections 4 and 5 present the functionalities that implement the MobileMap front-end and back-end respectively. Section 6 shows and discusses the experimental results. Finally, Section 7 presents the conclusions and future work.

2 The Urban Emergency Response Process

The emergency response process typically starts when a command center receives a phone call indicating an emergency situation (Fig. 2). Then, the command center turns on an alarm and assigns one or more fire trucks (belonging to one or more firefighting companies) to the incident. The number and type of fire trucks being assigned is a decision made based on the information gathered from the phone call (e.g. emergency site, and the event size and type). In addition, the command center could ask for additional support from police or ambulance services.

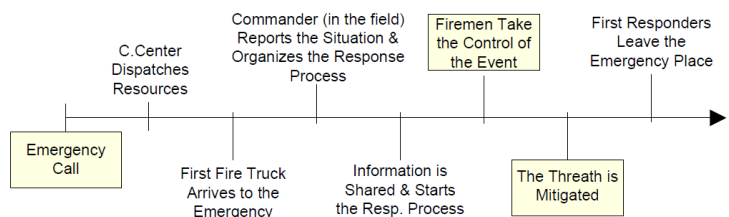


Fig. 2. Summary of the emergency response timeline.

It is well-known the time spent to take control of critical events is very important in urban response processes (Godschalk, 2003; Mendonça, 2007; Ochoa, Neyem, Pino, & Borges, 2007). Human lives and infrastructure damages frequently depend on it. However, the time currently spent by fire trucks to reach the emergency site strongly depends on the drivers' skills.

Once the first officer arrives at the emergency (usually with the first fire truck), he/she becomes the incident commander (IC) for the emergency. The IC collects information about the affected area, makes a diagnosis of the situation, reports the crisis features to the command center, and organizes the response process.

The information given by the IC is broadcast by the command center to the firemen in the field and to the firefighters currently moving towards the emergency site. Thus, when the following fire trucks or firemen arrive to the site, they already know some details of the situation. However, they need to contact the IC to receive orders and the specific information which must be known to perform the relief activities.

Sometimes the supporting information (e.g. maps or evacuation routes) and/or the incident commander are not easy to find; besides, the radio channels may be busy or unavailable to transmit requests from the firefighters. Once the firemen find the IC, he/she is usually busy or dealing with urgent issues. Since these firefighters are arriving in stages, the commander becomes a bottleneck in just few minutes. Consequently, many firemen in the field have to improvise their response actions, sometimes with little supporting information or none at all.

The level of communication and coordination presented by the firemen during an emergency affects the time required to take control of the event, and also the time required to mitigate it. It has direct consequences on damages to citizens and property. Therefore, any solution to increase the communication and coordination during response processes will bring an important contribution to society (Turoff, 2002; Kean et al., 2004; Yuan & Detlor, 2005; Aldunate, Ochoa, Pena-Mora, & Nussbaum, 2006; Ochoa, Neyem, Pino, & Borges, 2007; Chen, Sharman, Rao, & Upadhyaya, 2008).

3 Related Work

During the last years, the scientific community has reported several IT solutions to deal with communication, coordination and decision making challenges in large-scale disaster mitigation (e.g. tsunamis, hurricanes or terrorist attacks). The proposals range from those focused on the communication and notification problems (Midkiff & Bostian, 2001; Meissner, Luckenbach, Risse, Kirste, & Kirchner, 2002; Smith & Simpson, 2005, 2009; Manoj & Baker 2007; Kanchanasut, Tunpan, Awal, Das, Wongsardsakul, & Tsuchimoto, 2007; Malizia, Onorati, Diaz, Aedo & Astorga-Paliza 2010), to those focused on information management, resource allocation and decision-making (Yuan

& Deltor, 2005; Alonso-Betanzos et al. 2003; Chen, Sharman, Rao, & Upadhyaya, 2008). Some examples of these systems are CATS (Swiatek, 1999), OpenGIS (Farley, 1999), DERMIS (Turoff, Chumer, Van de Walle, & Yao, 2004), Sahana (Currion, de Silva, & Van de Walle, 2007), DUMBONET (Kanchanasut, Tunpan, Awal, Das, Wongsardsakul, & Tsuchimoto, 2007), Eplan (Zhang & Li, 2008), and MESA (Mesa, 2009).

Solutions focused on communication try to deal not only with most problems discussed in the previous sections, but also with others that occur in large disaster relief efforts. These solutions typically involve novel communication infrastructure (e.g. WiMax mobile) and usually satellite communication. Although they provide strong communication support in the affected area, they require expensive equipment and supporting infrastructure e.g., mobile antennas deployed on communication trucks (Bradler & Schiller, 2009). Clearly this is not the technology we may consider usable in regular urban emergencies by volunteer firefighting companies.

Solutions focused on information management and decision making support the work of personnel in the command center. There, the activities are different than in the emergency site. The information collected by emergency management systems is typically used to make decisions and coordinate the first responders' activities. These systems are particularly useful to coordinate large disaster relief efforts, but they also require strong communication support. Fig. 3 shows the coordination room of the Nunoa Command Center (in Santiago, Chile). This organization participated in the development and validation of the MobileMap tool.

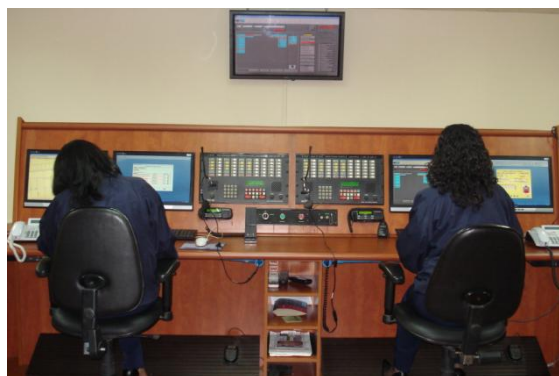


Fig. 3. Nunoa Command Center in Santiago, Chile.

There are few works reporting solutions usable by firemen in the field to support typical day-to-day emergencies (e.g. car accidents or small fires). One of these works was proposed by Schöning, Rohs, Krüger, & Stasch (2009). These researchers propose a system that runs on mobile computing devices using augmented reality to support the communication of spatial information in an emergency response scenario. Although this proposal seems to be useful to deliver blueprint or sketches, it requires strong communication support.

McCarthy, Edwards and Dunmore (2006) proposed an autonomous communication infrastructure that supports the activities of a mountain rescue team. Although the infrastructure was not designed to support high concurrency in the access to the channel, this solution could provide some communication support to firemen in the field.

There are also well-known commercial solutions to provide communication support to firemen in the field. However, the volunteer nature of Latin American firefighters implies most of such solutions are inappropriate for them (Currion, de Silva, & Van de Walle, 2007). The main causes are typically two: (1) fire companies are not able to pay the cost of buying and using the product, and (2) the tool should be very simple and easy to use, because these organizations involve personnel with wide range of training and skills. Some of them may even have problems to use IT solutions.

The closest open source initiatives trying to improve the firemen's communication support in the field are the authors' previous works (Aldunate, Ochoa, Pena-Mora, & Nussbaum, 2006; Guerrero, Ochoa, Pino, & Collazos, 2006; Ochoa, Neyem, Pino, & Borges, 2007). The tool presented in this paper is an evolution of the authors' previous proposals.

4 MobileMap: Front-End Functionality

Fig. 4.a shows the MobileMap main user interface. This tool was initially designed as a Geographic Information System (GIS); it is able to run on a hand-held device, and it supports the work of firefighters in the field (Fig. 4.b.). The tool allows firemen to ask for several types of geographic information, e.g., maps of particular areas, location of a specific street or fire trucks attending the emergency. Such information is stored locally in each device to avoid using radio channels or the GSM network (for cellular phones).

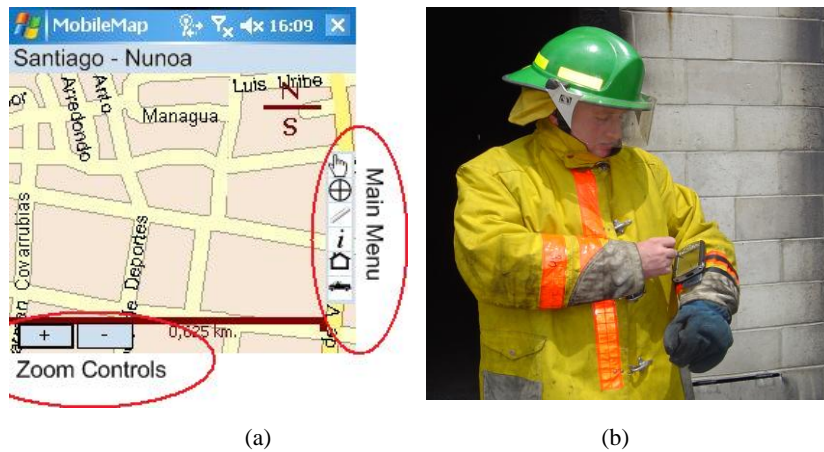








Fig. 4. (a) Main user interface of MobileMap, (b) Use of the tool.

After several evaluation processes, MobileMap is evolving towards the inclusion of communication and decision making support for firemen in the field. The current version of MobileMap allows firefighters to interact with the command center using requests and responses sent through the GSM network. If such network is not available, the application is able to automatically create a Mobile Ad hoc Network (MANET) among the computing devices deployed in the emergency place. It allows firemen to access shared information (e.g. a map of the affected area), deliver alarms or even listen to voice messages on-demand, without interfering with the radio channels. Table 1 summarizes the functionality available through the main menu, and the following sub-sections explain the services behind each menu option.

Table 1. MobileMap main menu.

Icon	Description
	Navigation. This service allows a user to navigate the maps using the stylus.
	Destination. It allows a user to select a destination point.
	Distance. It is used to compute the distance between two points.
	Information. It allows a user to select a specific interest point category to be displayed on the map. It also helps to share information with the command center and other firefighters.
	My current location. This option shows the current location of the user on the map.
	Fire trucks. This option displays the location of all fire trucks attending the emergency by instructions from the command center.

4.1 Navigation Service

Each computing device using MobileMap has pre-loaded maps of the city, including several levels of zoom (see *Zoom Controls* in Fig. 4.a.) and interest points (e.g. hydrants, hospitals, police stations and schools). It provides autonomy to firemen (in terms of supporting information for decision making) and also helps reduce the demand for radio channels.

The *navigation mode* helps firemen to retrieve the geographic information stored in their mobile computing device. This is the default mode of this tool; however, MobileMap has other user modes which allow to do further operations on the maps. It is possible to change the user mode and access additional functionality by selecting the options in the main menu.

The navigation service allows firefighters to surf the maps in two ways: on-demand or automatically. On-demand navigation requires the user to click on the hand-held screen with the stylus. MobileMap will consider that point as a gravity point, thus producing a shift on the map in the direction indicated by the user.

Automatic navigation is available for devices embedding GPS. It focuses on the user's current location and automatically shifts the map according to the person's movement.

4.2 Destination Service

This service allows a user to select a destination using an address or a tuple: latitude, longitude. Fig. 5.a shows the destination input form. In case of an emergency, the destination point can be consumed through a Web service exposed by the command center. Thus, firemen reduce time and errors when identifying the emergency location.



Fig. 5. MobileMap destination service.

Once a destination address has been selected, MobileMap shows two arrows pointing from the user's current location (Fig. 5.b). The black one indicates the direction in which the user (or the fire truck) is moving, and the white one shows the direction in which the user must move to get to the destination point. This functionality helps to arrive faster to the emergency site, not only to fire truck drivers but also to firemen going to the target location in their own vehicles. If they arrive faster, the mitigation process can start earlier, and thus, reduce the damage to citizens and property.

4.3 Distance Calculation

This functionality computes the distance between two or more points chosen by the user by clicking on the hand-held screen. The screen shows the segment as a black line on the map, and the calculated distance is indicated in the upper-left corner of the user interface (Fig. 6).



Fig. 6. Distance calculation in MobileMap.

This information is useful to try to anticipate the first response actions while the fire trucks are still going to the emergency site. For example, it is possible to know the distance to the closest school, in order to evaluate a possible evacuation of the building in case of a fire. It is also useful to determine the size of the affected area. Any decision that firemen can anticipate will contribute to reduce the time required to control the emergency.

4.4 Information Management

This functionality allows a firefighter to perform three operations: review emergency information, show information layers on the map, and exchange information with the command center and other firemen. Fig. 7 shows the three ways of displaying information about the emergencies.

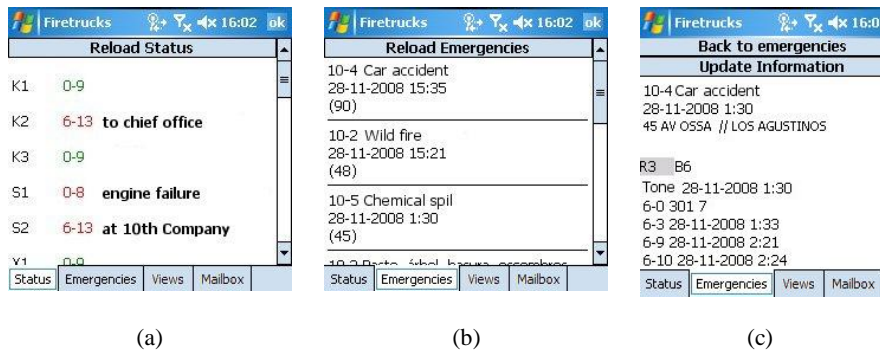


Fig. 7. Information management in MobileMap.

Fig. 7.a shows a list of fire truck codes, the truck status code (e.g. 0-9: available), and additional data about each vehicle. If the user chooses the *emergency* option, a list of current emergency situations is shown on the screen (Fig. 7.b). It is possible to access the details of an emergency by selecting it (Fig. 7.c). All this information may be selectively retrieved from the command center when the device is connected to a GSM network.

On the other hand, if the user selects the *views* option s/he can choose which pre-loaded information (i.e. interest points) they want to see depicted on the map. Fig. 8.a shows the form available to select such data, and Fig. 8.b presents the resulting map showing the interest points. It is possible to access institutional information, such as its phone numbers or its working hours, by clicking on the corresponding icon. This information could be useful to trigger the response process even if the firefighters have not arrived at the emergency site. For example, in case of a flood or a fire, police officers can already trigger the evacuation of the most vulnerable buildings nearby.

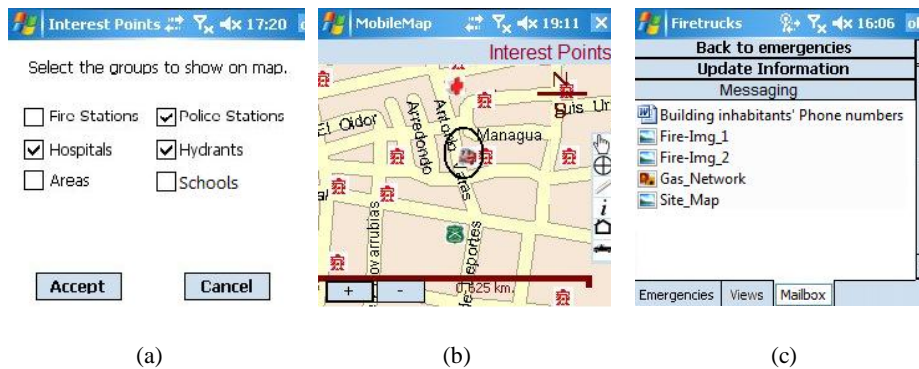


Fig. 8. Information deployment and exchange.

Finally, if the user selects the *mailbox* option, s/he accesses a shared folder that allows exchanging information with another fireman or with the command center. The information exchange can be done through Wi-Fi or GSM networks, depending on the communication networks availability. Data exchange with the command center is typically done using GSM. However, if such network is not available in the emergency site, the application will use a Wi-Fi-based Mobile Ad hoc Network (MANET) to provide data exchange among firefighters in the field. This tool inherits the capability to automatically form these networks, because it is based on the SOMU platform (Neyem, Ochoa, & Pino, 2008).

Fig. 8.c shows the list of files a handheld device shares with the command center and other peer devices. The maps of the affected area or any other data can be shared in an easy and fast way through this mechanism. This type of communication does not interfere with the radio channels.

The information shared by the command center through the mailbox includes a kind of log record with the voice messages transmitted by the main channel. These messages are transformed in audio files, almost in real-time by a daemon process, and they are ordered chronologically. Thus a firefighter that has lost some messages on the radio, can listen to them (on-demand) through his mobile device. It reduces as much as possible the use of the radio channels for information retransmissions.

4.5 User's Current Location

This function reloads the map and the information deployed on it, centering the image on the user's current location. A user may need to come back to his/her current location (e.g., because s/he got lost) during the map navigation process. This menu option allows users to do that simply and quickly.

4.6 Fire Truck Location

Similar to the information management system, this option allows deploying on the map the current location of fire trucks attending each emergency situation. Fig. 8.b shows the current location of a fire truck, and also several other interest points around it (e.g. hydrants, hospitals and police stations). Provided vehicle location is changing, the handheld updates such locations on the map while the truck is on the move (i.e. *automatic navigation*).

The position of the fire trucks is obtained based on the location of the handheld belonging to each vehicle, which includes a GPS. Each handheld informs its position to the command center once the current position has changed in at least one hundred meters (in any direction) respect to the previously reported location. Thus, parked trucks do not need more than one message to report their position.

The handheld belonging to a truck stores the list of instruments/tools available in such vehicle to support emergency relief activities; particularly the special ones, such as chain saws, drills, oxygen masks, sonar or big water tanks. This list is reported to the command center.

Firefighters and other trucks selecting the *fire truck* option on MobileMap retrieve data on trucks from the command center. Knowing the location of the trucks and equipment is important for the response process, because it allows the incident commander to know, which resources will be arriving to the emergency site and the estimated arrival time. The strategy to deal with an emergency sometimes changes because a particular tool has just arrived in a fire truck. The effectiveness of the response process could depend on whether or not the incident commander has this information on time.

All functionality implemented on MobileMap allows accessing the (local or remote) shared information on-demand. It reduces the need of using the radio channels and provides firemen a better support to make their decisions. Improvisation will be always present in emergency scenarios, however accurate and on time information can help firefighters to make timely and effective decisions. Experimental results show the firemen feel the tool helps them to be much more confident when improvising.

5 MobileMap: Back-End Functionality

MobileMap uses a service-oriented architecture, where each handheld device and command center is a potential service consumer/provider. It is possible to identify three types of nodes in that scenario:

1. *Command centers*, which do not report their location or their list of resources. These nodes expose a set of services allowing the described operations. For example, they provide services to inform/retrieve the location of the trucks and the list of instruments/tools they contain, and the current emergency situations.
2. *Fire trucks*. By default, these nodes report their location and equipment to the command center. However, they expose a service that provides the same information to other fire trucks or firefighters using alternatively a GSM or a Wi-Fi network. Firemen can take advantage of this functionality when they are co-located in the emergency site, and connected through a MANET.
3. *Firefighters*. These nodes typically consume information from command centers or fire trucks, and exchange files and messages with any user type by using a mailbox system. These functionalities give firemen in the field some information autonomy and reduce their dependency on radio channels.

5.1 MobileMap Basic Architecture

The application has a client-server architecture. The server runs in the command center and the clients run on handheld devices used by firemen in the field or in fire trucks. Fig. 9 summarizes the server architecture.

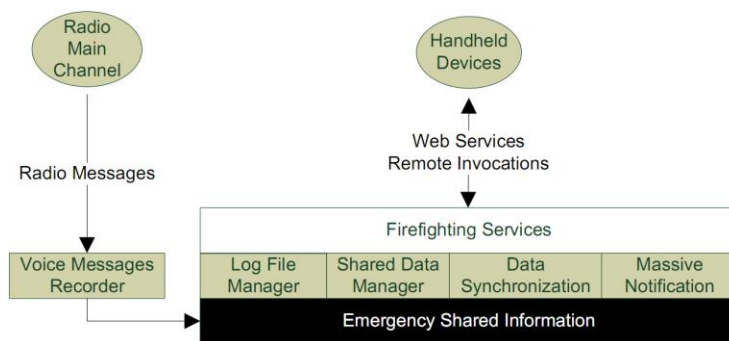


Fig. 9. Architecture of the MobileMap server application.

The server mainly acts as information repository and deliverer. It gets the information sent through the handheld devices (e.g. pictures or maps) and delivers them to any user requesting them. Furthermore, a voice recorder processes, captures and stores, almost in real-time, the voice messages delivered through the radio main channel. Such messages, which usually last between 10 and 15 seconds, are recorded in audio files and stored in chronological order. The audio files are shared by the command center; therefore they can be retrieved by firemen or fire trucks. All the shared information in the command center is shared in the same way.

The MobileMap client architecture is shown in Fig. 10. One of the most important components of this architecture is the *Map* class, which is in charge of retrieving the information from the local repository (e.g. maps and interest points) and showing the map on the user interface. The user interface implements a listener process that detects and processes the clicks on the screen. This listener triggers the corresponding operation (e.g. a shift of the map) depending on the application mode and the click location. The map class uses the *Fire Truck* and *Interest Point* classes to deploy information on the map.

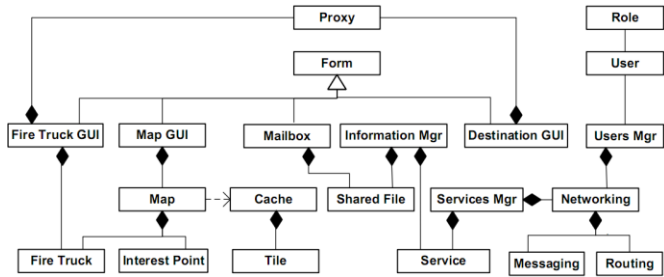


Fig. 10. Architecture of the MobileMap client application.

The map information is stored in *Tiles*, with the corresponding zoom level. MobileMap uses a *Cache* memory space to keep data, which could be frequently required in order to provide a good performance to the application.

All application forms used in MobileMap inherit from the *Form* class, and they represent application forms like those shown in the previous figures. Provided all information used by MobileMap is stored and exchanged using XML files, the *Proxy* class is the component responsible for managing them.

The *Mailbox* class implements an I/O buffer that allows the application to exchange files. The files are shared through services that use the *Networking* services to be transported. These services are also in charge of hiding the communication details to mobile users (e.g. a reconnection to a MANET or getting an IP address).

MobileMap also involves three processes acting as managers: *ServiceMgr* (it manages the invocations from/to remote nodes) *InformationMgr* (it receives and delivers shared files) and *UsersMgr* (it manages reachable users and roles). The next sections explain some of these components in detail.

5.2 Management of Graphical Information

The map view shown on the user interface is based on a matrix of four by four tiles (Fig. 11). Each tile is a PNG file, which has been previously loaded, in the mobile device. Each zoom level has a particular set of tiles that are used to compose the maps. When a user changes the zoom level, the application changes the set of tiles to be used.



Fig. 11. Examples of tiles used by MobileMap.

The use of graphical information based on tiles responds to the need of providing a good application performance to the user. When a user requests a map shift during a navigation, several tiles are re-drawn; however just a few of them are retrieved from the tile local repository. The cache class keeps these images in memory and it uses a LRU (Least Recently Used) policy to implement the tile replacement process. Since the maps are based on PNG files with geo-referenced corners (i.e. tiles), the information source to create the tiles could be any Geographic Information System (GIS) having that information.

5.3 Networking Issues

The message exchange, the capability to expose/consume Web services and the MANET communication services have been inherited from the SOMU platform (Neyem, Ochoa, & Pino, 2008), which is part of the authors' previous work.

MobileMap has two processes to manage the networking issues; one for GSM and another one for Wi-Fi networks. The first one, which is used by default, allows exchange of information between a handheld device and the command center. This communication service is used, for example, to send pictures from the emergency place to the command center. In such case the picture is serialized, transmitted through the network. Following the same strategy, any other type of resource can be shared through the GSM network.

The process managing the Wi-Fi network is used if the GSM network is not available. This process provides services to support communication among firemen in the field. This process assigns an IP address to the handheld device following an algorithm that randomly assigns the last two numbers of the *Host Identifier* (i.e.: 172.145.xx.xx). In case of IP collisions, they are detected and re-generated dynamically.

This networking process detects peers at a one-hop of distance and automatically forms a MANET by negotiating with the processes running in the other mobile nodes. It allows message delivery and file transfer among the network members. The authors are currently working to include live voice messages transmission on the MANET. This Wi-Fi network manager uses a component that provides routing on the MANET, thus it is possible to interact with mobile nodes located at more than one-hop of distance.

5.4 User Management

The network manager (in each mobile node) keeps an updated table with the current version of the network topology. It includes the IP address, the distance to each remote node and the virtual ID of the remote users; it is explained in detail in Neyem, Ochoa, & Pino (2009). Fig. 12 shows an example of the list of firefighters connected to the MANET during an emergency.

The first user of the list is always the local one. It is represented with a color different to the rest of the users. The users indicated in the list are those who are reachable (through one or more hops) for the local user. Users represented with a blurred icon are persons that are temporarily unreachable for the local host.

If a user with a blurred icon does not become reachable during a configurable time period (e.g. 30 seconds), s/he is removed from the connected users list. This users list can be used to support on-demand peer-to-peer interactions (e.g. messaging or files transfer).

The application allows assigning a role to each connected user. However, the role acts only as contextual information in the tool current version. Such contextual information can be represented by coloring or labeling each user's icon.

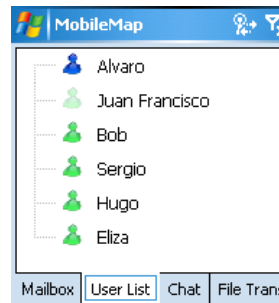


Fig. 12. MANET users.

5.5 Log File Record and Processing

The client and server components of MobileMap record a log file in a distributed way. The log file stores information related to interactions in which the node (i.e. client or server) was involved during an emergency. The information is stored in a local XML file, and it includes a timestamp for each recorded interaction.

The log file is not typically useful during an emergency. However it can be highly valuable after that, in order to understand the interactions during the response process and get lessons for future situations. The processing of the log file involves three steps: information recording, integration and analysis.

The information recording is an automatic process, embedded in MobileMap, which is transparent for the users. The information integration is a batch process that requires each mobile unit (i.e. firemen and fire trucks using the application in an emergency) to send its local log file to the command center. Since these are XML files, the tool uses a *μXML Synchronizer service* (Neyem, Ochoa, & Pino, 2008) to get an integrated XML file. Such file contains the sequence of all recorded events during the emergency. The sequencing process is initially done by the *μXML Synchronizer*, however manual adjustments are usually required due to the differences among the internal clocks of the participant computing devices.

Finally, the information analysis is done based on the resulting log file. Because this file is not easy to read by human beings, it is recommended to show indicators based on the recorded information. At the moment, MobileMap does not provide support for this analysis phase. However, this functionality is already under development. These analysis tools will allow firemen to learn from past experiences and get lessons for the future. The tools will also allow evaluating the efficiency and effectiveness of the several response alternatives for a particular crisis situation. This could contribute to improve the techniques, processes and protocols already used by firefighting organizations. Some of the key processes that can be influenced are the following ones: search and rescue, evacuation, risk reduction, and event isolation and mitigation.

5.6 Implementation Issues

This application was developed using C# and the .NET Compact Framework, version 3.5. Therefore, the tool is able to run on computing devices using WindowsXP or Windows Mobile 5.0 or higher.

Most of the supporting files, such as the users list of a MANET, are represented as XML files. This data format helps to deal with information interoperability and it simplifies the information processing. Similarly, the interaction services are implemented as Web services to deal with interoperability and simplicity issues.

These design and implementation decisions produced a lightweight and high performance product. MobileMap has been used on PDAs, smart phones, netbooks and laptops with MS Windows as operating system. The next section presents the obtained results during the experimentation process.

6 Experimental Results

This application was initially tested by the authors using regular cars to simulate fire trucks. MobileMap was run on several PDA models; all of them alternatively with GPS and Wi-Fi and EDGE connection capabilities. The GPS

location uncertainty was around 20-30 meters, which is acceptable for the type of emergency response processes we are handling.

After the first round of tests, MobileMap was used to support typical emergencies in Santiago, Chile. The Nunoa command center and the 2nd Fire Company did these tests. The next section presents these results. The authors also conducted a comparative study on firemen interactions with and without MobileMap. The goal was to understand the main limitations and contributions of the current solution. The results are presented in section 6.2.

6.1 Evaluation in Real Emergencies

Initially, the firemen received a 30-minute training process before doing the tests. Then, they were asked to try the application. The participants were three drivers, five decision makers (i.e. three firefighters in charge of fire trucks, and two chiefs of the command center) and five regular firemen.

Users working on the command center utilized MobileMap running on a desktop PC. The firemen in charge of a fire truck acted as drivers' assistants during the trips to the emergency site. Then, they acted as incident commanders. Two of these persons used HP IPaq hw6945 PDAs, and the third one utilized a Samsung NC10 netbook with a GPS.

Finally, the regular firemen participating in the experiences utilized handheld devices. Two of them used an IPaq hw6940 PDA, and the other three utilized smartphones: two HTC Diamond Touch and Samsung Omnia. The authors lent part of this equipment to firefighters, and the rest were personal devices of the firemen participating in this process.

After MobileMap was used in more than 10 emergencies, the authors organized a focus group to ask the users' opinion. Fire truck drivers and their assistants considered the application helped to reduce the arrival time to the emergency sites (Fig.13) particularly in the periphery of the city, where the street names are usually unknown to them. In fact, during a fire, a truck using the tool arrived before another one without it, despite the fact it had to travel a longer distance. The reason was the driver of the first truck confused the location of the emergency, and the second one trusted the information shown by MobileMap (which was retrieved from the command center).

The improvement in the arrival time could make a great difference on the consequences of many emergency situations. Although the improvement was estimated by fire truck drivers to be between 15 and 25%, the reduction of the error rate when they look for an emergency location could considerably improve the arrival time. The authors are already analyzing the possibility of embedding information about the traffic congestion into MobileMap. This would also help reduce the arrival time.

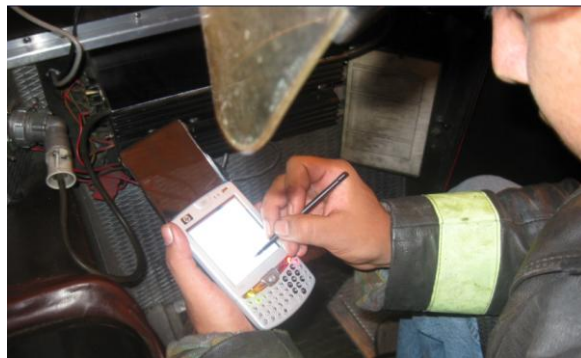


Fig. 13. Fireman using MobileMap to help guide a fire truck to the emergency site.

Incident commanders felt comfortable with the information they could retrieve through the application; particularly when MobileMap interacted with the command center (e.g. to retrieve the emergency locations) and the involved trucks (e.g. to retrieve the fire trucks equipment). These incident commanders believed they could accomplish more work during the trip to the emergency than before, because they were able to know more information about the emergency (e.g. retrieve a photo sent by a fireman in the site to the command center) before arriving there. Thus, they reduced time for diagnosing and response planning, and consequently, the time required to take control of the situation decreased. However, they were not able to estimate a percentage of time reduction for controlling the emergency.

Decision makers in the command center just monitored the activities of the firemen using MobileMap. They were able to track (in real time) the fire trucks route towards the emergency site, and also monitor the information requested by MobileMap users in each stage of the emergency process. They thought the tool was useful to reduce the fire trucks arrival time and also to share graphical information. However they were not sure about the application usefulness to reduce radio channels usage. A later analysis of the emergency records showed the number of exchanged messages was 30% lower than in similar emergencies in which MobileMap was not used.

Regular firemen were happy to be able to retrieve on-demand the radio messages and also the information shared by the command center and other mobile units. They felt more confident when they had to improvise an action,

because they had additional supporting information. They also felt safer knowing they were able to deliver a general alarm through the application, in case their lives were at risk.

All of them considered the tool was intuitive and had good performance. Incident commanders and regular firemen estimated the requests for radio communication may be reduced by half when MobileMap is used. However, decision makers on the command center did not notice a real improvement.

During this interview process, the users also asked for possible extensions of MobileMap. Drivers requested a voice system to help guide the truck, because the tool currently requires an assistant using the application to support the driver. Incident commanders asked us for a mechanism allowing them to be connected all the time. Decision makers asked for a user-friendly representation of the information stored in the emergency log files. Regular firemen asked for a voice IP channel allowing them to carry on live voice interactions in the field. These requirements will be considered for future versions of the software.

6.2 Interactions Analysis

The authors analyzed the radio messages from six normal emergencies, which were recorded by the command center when MobileMap was not used. The emergencies were three fires and three car accidents. In case of big fires (e.g. affecting a building or a store) the number of messages delivered by the radio is around 350 and the duration of each one is about 10-20 seconds. In case of a fire in a house or apartment the number of messages is reduced to 270 approximately, but the duration of each one is similar to the previous case. In car accidents, the authors identified about 200-300 messages also with a duration similar to the previous scenarios.

The authors analyzed the content of the messages and concluded that half of the information requested or delivered through the radio channel would be available in MobileMap, if they were used in those emergencies. This estimation is similar to those made by incident commanders and regular firemen involved in the evaluation process. Therefore, it seems the tool would have potential to reduce the radio channels usage.

The authors integrated and analyzed the log files of four emergencies in which MobileMap was used: three fires and a car accident. The fires involved two houses and an apartment, and they had between 165-190 radio messages each. Although the reduction in the number of messages is less than 50%, it is important to consider that just three to five persons were using MobileMap in these emergencies. There were (on the average) 23 local information requests per mobile unit using MobileMap. If we consider the proposed solution can scale considerably in term of users (i.e. provider and consumers), it is not easy to establish which is the real message reduction rate generated by the tool. This is because today there is an important unsatisfied demand for communication channel time (when radio systems are used) during emergencies. Such demand will be then assimilated by MobileMap, and thus the demand for message exchanges will be distorted.

In case of the car accident, three persons used the application, and the response process had 127 messages. There were (on average) 34 requests for local information per mobile unit. These numbers could be showing the information deployed on MobileMap really helps to make decisions in the field. This capability of the response process was not available when firefighters used radio systems only.

Finally, the authors showed the integrated log files to the decision makers. They found such information valuable; however, a user-friendly representation of that information is needed in order to analyze it properly and learn lessons for future emergencies.

6.3 Cost Analysis

The operational cost of this solution in Chile is about US\$ 10 per fire truck per month, and US\$ 50 for the command center per month, which is acceptable for their budgets. The viability of assuming these costs was verified with the firemen participating in the evaluation process.

The cost for regular firemen could be up to US\$ 10 extra in their regular cellular phone monthly plan, for a network plan with unlimited data transfer (interactions on the MANET are free). However, the focus groups conducted with firefighters indicate that about a third of them have a cellular phone able to run MobileMap (or a light version of the tool), and a plan for unlimited Internet access. Therefore, in these cases the proposed solution has no additional cost for these users. If we consider that the cost of communication and mobile computing devices is currently decreasing, we can assume this situation will become more widespread in the future.

Since MobileMap is not being proposed to replace the current radio system, it does not make sense to compare the acquisition and maintenance costs of both systems. However, it is possible to show the cost of the proposed system is affordable for volunteer firefighting organizations. For instance, each Chilean volunteer fireman, who wants to have a radio device, must buy it. The cost of a regular one (brand new) is around US\$ 450, while a used one costs around US\$ 200. These figures show that acquisition of a smartphone may be a reasonable expense for most firemen, considering these devices can also be used as regular cellular phones. Radio communication systems have a monthly

maintenance that must be assumed by each fire company; however, when the system uses the cellular network the cost of maintenance is assumed by the service provider (i.e. the telecommunication company).

If the cost of both solutions is similar, then the discussion must be focused on which alternative provides better services and capability of evolution. Although radio systems have shown to be useful in emergency relief scenarios, it is also well known this technology has already reached the limit of the services it can provide (Kean et al., 2004; Aldunate, Ochoa, Pena-Mora, & Nussbaum, 2006; Ochoa, Neyem, Pino, & Borges, 2007; Carver & Turoff, 2007). In the case of mobile computing solutions supported by advanced networks (e.g. MobileMap) the situation is different. These solutions can provide communication support similar to the radio systems, transmit digital information and address users (and groups of them) in a more efficient way. In addition, several quality issues, such as security and privacy, can be addressed on these new systems. In other words, current radio systems supporting emergencies may be replaced in the future by solutions using advanced communication networks. The two issues that still make the radio systems necessary are their usability and interoperability.

7 Conclusions and Future Work

This paper presented a mobile collaborative application named MobileMap. This application was initially designed to help firefighters to arrive faster to the emergency site, to allow them to exchange digital information during emergency response processes and to reduce the need for radio communication. However, the current version of the tool also supports the decision making process carried out by firefighters in the field and the emergency learning process (after the crisis). The tool was tested in simulated and real emergency scenarios. The obtained results show the firefighters believe that MobileMap helps reduce the arrival time to the emergency place. Moreover, they feel more confident while making decisions, and they arrive to the emergency site with more information than in previous situations. We suspect this application could also help reduce the time required to control the emergency, which typically increases the protection to human life and property.

The results also show the tool may help reduce the use of the radio channels. However, the percentage of reduction will depend on the number of persons using the application. The more people using the tool, the more important the reduction in radio usage will be.

MobileMap allowed the exchange of digital information with low operational cost during these preliminary evaluations. These interim results indicate the tool may help overcome most limitations stated in section 1. The authors hope this initiative helps to increase the number of lives saved by firemen during emergency situations.

The next steps in this initiative are two. On the one hand, it is important to evaluate MobileMap in daily emergencies, involving several fire companies, using a more formal evaluation approach. This will allow us to understand the strengths and limitations of MobileMap, as well as add useful functionality to the current solution.

On the other hand, the authors plan to spread this solution as much as possible to obtain feedback from several sources. For example, the tool could be tested in public health services to see if it may also be applicable to them. Other relevant organizations (e.g. police) are faced with problems similar to firefighters' when traveling to an emergency and at the emergency site. Therefore, the solution could impact the work of several organizations as well.

A long term goal of this initiative is to enhance MobileMap in order to propose it as a replacement of the current radio systems. The authors think that advanced telecommunication networks such as LTE (Long Term Evolution), also known as 4G (Dahlman, Parkvall, Skold and Beming, 2008), would allow MobileMap to provide an improved support to firefighting.

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