A Geo-based Application for the Management of Mobile Actors during Crisis Situations

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ABSTRACT

The widespread availability of network-enabled handled devices has made the development of pervasive computing applications an emerging reality particularly suitable for managing emergency/disaster situations. Moreover in emergency management scenarios, Geographic Information Systems (GIS) are gaining momentum for their capacity to capture, analyze and manage geo-referenced data. In this paper we discuss an architecture designed to support rescue teams operating in outdoor environments and equipped with mobile devices working in a P2P fashion within a Mobile Ad-hoc Network (MANET). Our system has been designed to effectively address the on-field working persons' need for geographic information that cannot be supplied by conventional paper-based maps. Our approach provides a transparent access to geo-information and to GIS functionalities, and it addresses issues specifically relevant to emergency management scenarios in open fields.

KEYWORDS

Emergency Management, GIS, Manet, Peer to Peer, Web Services

INTRODUCTION

The term *"emergency management"* means all the coordinated activities carried out to prepare, support and re-establish social structures when natural or human-made disasters occur.

A key role in emergency management is played by *GIS (Geographic Information System)*, a system for capturing, storing, displaying, editing, analyzing and managing data and associated attributes that are spatially referenced to the Earth (GIS for Emergency Management, 1999). In all aspects of emergency management, geospatial data and tools can contribute to the saving of lives, the limitation of damage, and the reduction of costs to society in dealing with emergencies. Responders who know where impacts are bigger, where critical assets are stored, or where infrastructure is likely to be damaged, are able to act more quickly, especially immediately after any disaster event when there is the greatest possibility of saving lives. In the last years massive investments have been made for a rapid growing and development of GISs exploiting the Web to export their functionalities (*WebGIS*), but the specific needs of emergency management - rapid operational capability and access to data, extensive planning and tools that work under the difficult circumstances of search and rescue - have rarely been addressed. Moreover numerous impediments exist to data sharing, including the lack of interoperability at many levels, the lack of knowledge about what data exist and where, and the lack of operational infrastructure in the immediate aftermath of disaster.

These topics were particularly important in the scope of a project[1] focused on Emergency Management. The architecture of the WORKPAD project (see Figure 1) consists of two typologies of users: *Back-End* and *Front-End* users. Front-End users are those operators who act directly in field during the disaster (ranging from firemen to voluntary associations). A single Front-End community is constituted by the operators of a team, commanded by a team leader, equipped with mobile devices (i.e. PDAs) and connected in a P2P MANET network that allows

[1] `http://www.workpad-project.eu`

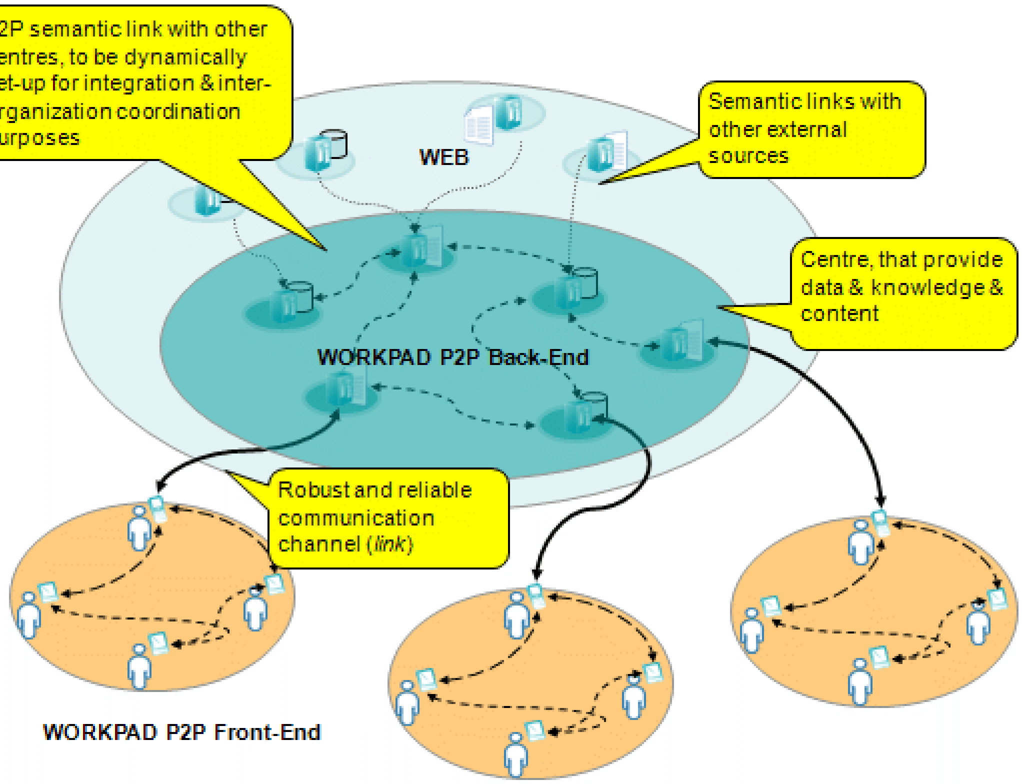

Figure 1. An overview of the WORKPAD architecture.

correct working of communications even in the absence of a fixed infrastructure. Back-End users are the operators who manage the situation from control rooms, by providing goals/instructions/information to Front-End operators. In this document we focus our attention on the WebGIS system realized in the project, both at the Front-End side and at the Back-End side.

The contribution of this work consists in the realization of an architecture to provide mobile devices in pervasive environments with *(i)* complex GIS functionalities, *(ii)* transparent geo-data retrieval, *(iii)* support for communications among team members to notify changes in the maps and to update the remote storage systems with on-field information. While a traditional GIS allows only to have a static interaction with the map, our system gives the possibility to use a set of high level tools to analyze geo data, treat satellite images and study the characteristics of the territory, making it particularly useful for the Emergency Management.

The next section shows a possible scenario concerning the imminent eruption of a volcano. Other sections of the paper, built around this example, describe:

- *Related Works*.
- *Back-End Architecture*, which addresses communication issues and deploys GIS functionalities as Web Services.
- *Front-End Architecture*, which represents the platform allowing the team members to invoke GIS functionalities to visualize/modify maps and to notify instantaneously possible modifications to other teams and to the Back-End system.
- *User Interface* at Front-End, which shows the GUI of the system and the steps carried out by the operators to face at best the emergency.

A RUNNING EXAMPLE

Let's consider the scenario of a powerful earthquake that shakes a volcanic region. Let's suppose that the INGV (National Institute of Geology and Volcanology) detects its epicenter near a volcano that dominates the region estimating a probability of 80% of an imminent eruption in the following hours. Therefore, a team is sent on the place to evaluate the damages produced by the earthquake and to take the first decisions about the evacuation of the area.

The operators have to retrieve information about:

- Locations of transportation routes, including road capacity, traffic flows, and workarounds.
- Demographic data at fine-grained levels of geographic detail stored in databases, providing information about the number of people in the area, age characteristics, the number of persons with disabilities, etc.
- Data about the locations of potable water lines, natural gas lines, oil storage facilities, electric lines, and communications lines. In addition, geo-spatial data about critical infrastructure, including bridges, aqueducts, hospitals, schools, etc.

Moreover the operators using communication systems capable of reporting the user's location, use several services to achieve their tasks, in particular they have to:

- Access and display maps, and perform other functions on geospatial data.
- Use a tool able to determine the magma flow in the case of the eruption in order to set a priority level in the execution of operator's tasks.
- Notify to the system and to other operators changes that may have occurred in the area.

Starting from this example, in the next sections we show how our system provides such services and information to support the on-field operators in facing the emergency.

RELATED WORKS

Several organizations and governmental commissions have confirmed the lack of appropriate instruments for analysis and decision support during the emergency situations (Successful Response starts with a map, 2007). They also pointed out that an important step forward can be taken by concentrating the efforts towards the improvement of rising geo-technologies:

- The P2P communication paradigm is going to be a very effective approach for the coordination and cooperation in outdoor environments (Gartner G., 2001) (Kellerer W. et al., 2005) afflicted by disastrous events (Bortenschlager M. et al., 2007), however there is still the need of an integrated Back-End system to support peers in order to address the issue of the limited computational power of mobile devices.
- The search for interoperability (Chen Y. et al., 2004), and for instruments to aid the discovery of the entities providing the needed data and geo-services (Alfinito M., 2007), has led to meaningful achievements in the path towards even more interoperable geo-systems, but such technologies have yet to be properly integrated to make useful information available during crisis situations.

GIS supports many aspects of Disaster Management planning, response and recovery. In this sense, important goals have been achieved by exploiting recently specified standards to develop WebGIS systems for accessing the heterogeneous data sources and the remote GIS functionalities (Fortunati L. et al., 2006). However, until now it has not been shown a clear intention to "glue" together such technologies in order to provide a software architecture focused on the support of the work of on-field teams during critic situations.

In fact we can still point out some deficiencies in such systems with respect to Disaster Management in mobile environments and to contexts in which the needed data come from different sources and in different formats:

- eMapBoard, a geo-collaboration (MacEachren A. M. et al., 2003) tool for Disaster Management developed by Geodan. It offers real-time analysis components (Resch B. et al., 2007). It is client/server-based and it is intended to be used in control centres. Hence, it lacks the support of operators using mobile devices.

- The Emergency Intercom[2] tool (developed by Commend International) supports action forces with an internal networked command-and-communication network and helps to rescue people and materials. A disadvantage of this system is that it is not designed for working at an intra-organisational level (e.g. fire-fighters are not able to get access to the system of paramedics).
- GeoMAC (by the Geospatial Multi-Agency Coordination Group) is a web-based tool originally designed for the fire managers to access online maps of current fire locations and perimeters (Wagtendon J.W. et al., 2004). Detailed and real-time information can not be provided and it does not allow distributed collaboration.
- Toucan Navigate[3] represents a P2P-based collaborative geographic information system that allows entire teams to concurrently see and interact with the same map regardless of their physical location. The changes are shared and updated with the rest of team automatically. However, it does not support mobile on-field operators.
- GeoConference allows to exploit the geographic data, using standard services. In a geo-conference, participants share information in a synchronized geo-referenced workspace (Siegel C. et al., 2005). The GeoConference system includes tools to manage users, workgroups and geo-data access, it is mainly used in the control centres but no real support for mobility is provided.
- ArcPAD is a mobile, client/server-based GIS software developed by ESRI[4]. ArcPAD uses handheld and mobile devices and provides field operators with the ability to capture, analyse, and display geographic information (ESRI, 2005). It cannot be used for ad-hoc and on-field collaboration.

All the systems described above are designed in a top-down way, that is they are focused on the static planning of the action and are oriented towards a more decisional approach to the emergency. On the contrary we realized an integrated cooperative environment based on a bottom-up approach more suitable to support on-field actions, giving priority to the dynamic aspects of the emergency management, without losing sight of the decisional issues that characterize critic situations.

We have built an integration software layer (Core + Wrapper) able to use the most advanced geo-standards and systems to process the user's requests in a transparent way. Our system exports its functionalities as Web Services (WS) and the final user can execute them through a Web interface, independently from the standard or the data format to be used.

Moreover, we have explicitly focused on the emergency outdoor team-work scenario: we have considered the importance of communications, situation reports, asynchronous notifications and we have integrated software modules to address such issues.

We have also developed a system that allows a team member to update maps and geo-information both in a permanent way (e.g., after periodical surveys on the territory in peace-time) and in temporary one (e.g., interruptions on a road network after an earthquake), separating the thematic layers of work in the database and overlaying them if necessary.

THE BACKEND ARCHITECTURE

In this paper we present an architecture that is able to bring important advantages in critic scenarios, where heterogeneity of resources and requests can be a decisive factor. Above all, this system is oriented to offer to field-staff the opportunity of exploiting the capabilities of GISs for the analysis of the territory, in order to realize a cooperative environment for the remote access to the most powerful tools for the study of geographical resources.

[2] `http://www.commend.com`

[3] `http://www.infopatterns.com`

[4] `http://www.esri.com`

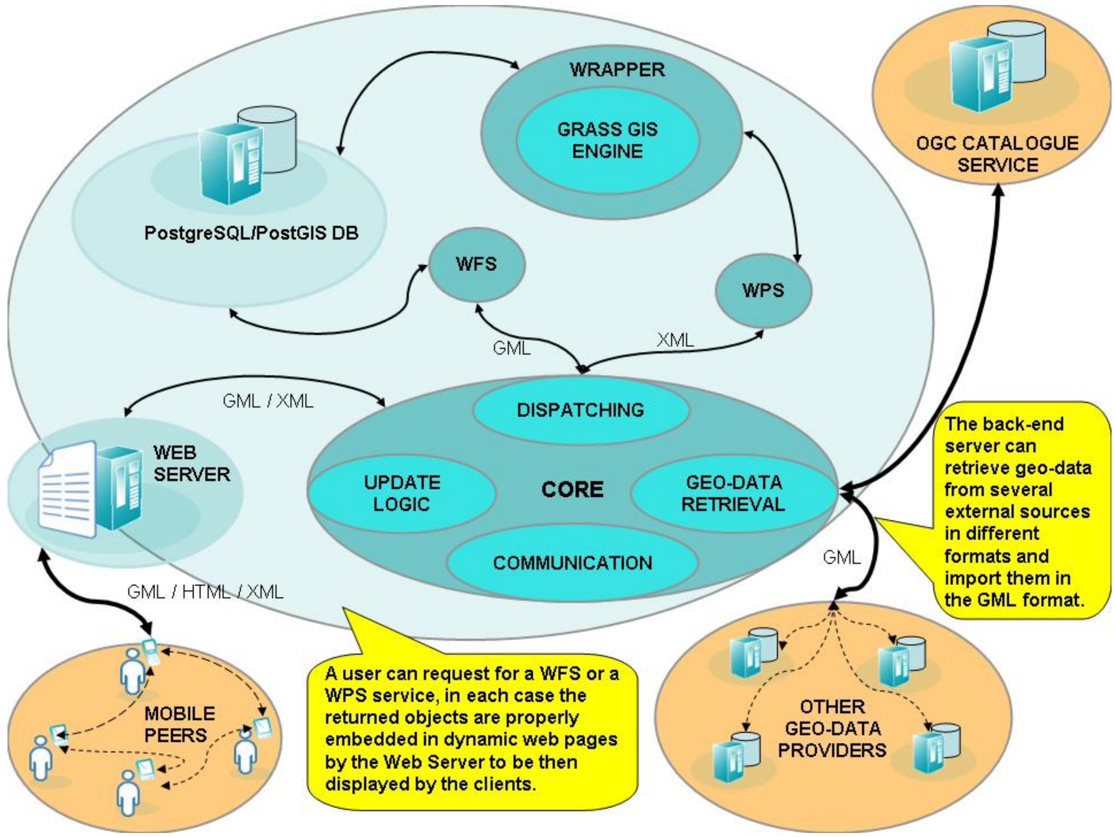

Figure 2. The Back-End architecture

We have selected Web Services (Alonso G. et al., 2003) as the development technology to specifically deal with geo-data. Through such an approach and thanks to the implementation of some standards defined by OGC[5], our system warrants to all the people involved in on-field activities access to the geo-data and to the complex GIS functionalities in a remote and platform-independent manner. In our approach we use the following standards to define the operations and the protocols for the research and the manipulation of geo-data:

- WFS[6]: The Web Feature Service specification defines the operations (create/delete/update/query) for accessing and manipulating the geographic features. We use it to retrieve from local databases the information about any geographic feature and to export them as a GML file.
- WPS[7]: In order to get the remote access to the potentialities of the "GIS heart" of our architecture, we chose to use the Web Processing Service, a standard that allows the users to remotely exploit GIS functionalities across a network as traditional WS.
- CAT[8]: The Catalogue Service specification defines the methods to find out where a geographic feature is stored in, all over the network, and to allow a public (or private) body to publish the geo-information it owns.

[5] The Open Geospatial Consortium is a non-profit, international, voluntary consensus standards organization that is leading the development of standards for geospatial and location based services.

[6] `http://www.opengeospatial.org/standards/wfs`

[7] `http://www.opengeospatial.org/standards/wps`

[8] `http://www.opengeospatial.org/standards/cat`

Mobile users browse dynamic Web pages to execute queries on spatial data or to remotely invoke GIS methods for geo-analysis and the results of such computations are visualized in the form of text or images, using two visualization formats:

- GML[9]: The Geographical Markup Language can be considered as the geographical declination of XML, it encapsulates both the informative (traditional database records) and the graphical (geometrical properties) characteristics of a feature so it is the ideal format for transporting and manipulating the geo-data between mobile clients and Back-End server.
- SVG[10]: The Scalable Vector Graphics is an XML-based file format for describing two-dimensional raster and vector graphics. It is characterized by the fact that images can be scaled indefinitely without loss of quality, while keeping the geometrical properties of the objects on the map and the topological relationships between them (Xiaoyong Su. et al., 2003). In our system the clients use it to display a map obtained in GML.

The Main Architectural Components

Figure 2 shows a graphical representation of the whole Back-End architecture.

Our architecture foresees the use of an Application Web Server (e.g., Apache Tomcat) able to manage all the technologies for the generation of dynamic Web pages containing all the objects that could be the inputs/outputs of an operation. Such an approach has been adopted to use a web-based interface to access the Back-End functionalities, exported as WSs. Through dynamically generated Web pages, the Front-End user can remotely invoke GIS functions or execute queries simply by clicking on the geographical features of interest and navigating the related menus. The aim of this approach is to replicate a GoogleMaps[11]-like system to manage geo-information.

To store locally the geo-data we needed a DBMS (DataBase Management System) able to deal with information concerning geometrical and topological characteristics of the features. PostgreSQL[12] is one of the best open source DBMS and, with its geographical extension PostGIS[13], it can effectively store information concerning geometrical and non-geometrical properties of the features of a map.

The GIS engine is the center of the complex operations available to the clients. The Geographical Information System we have used in our project is GRASS, probably the most powerful and widely used open source tool for geo-analysis. GRASS was originally developed as a desktop system to support the analysis of geographic data. Since the hardware limitations of mobile devices would not allow to run such a powerful and computationally heavy application, we have integrated it into our Back-End system to make its modules remotely available and largely useable as WSs. GRASS is a C-based Free/Open Source Software (FOSS) product, and in order to make it able to interoperate with different languages we built a Java wrapping layer around it. Such a wrapper is a crucial portion of the Back-End architecture, being the “bridge” between the implementation of the WPS interface and the GRASS engine. The Wrapper fulfills the function of mapping each module to its corresponding “WPS entry” and of converting the data format to correctly submit them to GRASS as inputs, or to the user as outputs.

The Emergency-oriented Modules

The internal implementation of the system is realized through an integration layer (the Core) that resides at the heart of the Back-End architecture (together with the GIS engine and the Wrapper). This represents an important aspect of novelty of our architecture. Such a layer holds the software modules suitable to address the various issues that can spring up when, during a critic situation, a rescue team (or several rescue teams) needs to access geo-data and to use different geo-analysis methods. In particular we address some meaningful issues:

- **Transparency of the geo-data retrieval:** when an information about a feature or a map is not found in the local database of the Back-End, the cooperative behavior of the system becomes more evident. In fact, such an event is

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[9] `http://www.opengeospatial.org/standards/gml`

[10] `http://www.w3.org/Graphics/SVG/`

[11] `http://maps.google.com`

[12] `http://www.postgresql.org`

[13] `http://postgis.refractions.net`

"caught" by the Core that switches from server to client and forwards the request for the missing map to other databases belonging to external organizations. Once the searched information has been found and obtained by the system, it is transferred using GML and then embedded by the Web Server in a dynamic Web page which is displayed by the client, extracting a SVG map from the GML code if needed.

- **Communication:** We can have more than one team and each team has a coordinator acting as a link between the team itself and the Back-End. The coordinator may need to know when another team joins or leaves the group, to be aware of which and how many forces are participating to the operations. So the communication module makes a note of which work-groups are currently joining the on-field action and of which events have happened in order to offer to an incoming team coordinator a report about the current status of the events and a chronology of the data and operations requested. Moreover this module can support any kind of further asynchronous communication.
- **Update logic:** The Core also covers the data storage; during an updating of a map it is important to distinguish permanent updates (e.g., resulting from periodical programmed surveys) from a temporary one (e.g., a street becomes inaccessible after the collapse of an adjacent building but it will back to its original state when the obstacles will be removed), to distinguish which has to be overwritten to the existing map and which has to be added, for example, to a temporary thematic layer.
- **Dispatching:** The user may need to visualize a map by accessing a WFS function or to make use of a more complex GIS computation through the WPS interface. In each case the requests coming from outside have to be properly forwarded to the right service and the responses have to be sent back correctly.

The whole system has been built using FOSS products. This aspect makes the range of application, the flexibility and the extensibility of the whole architecture virtually infinite. Our intention was to create a platform that can be adapted to the needs the personal responsible for rescue missions meet during their work. Indeed, the operators can develop their own module and add it to the existing system, so we could have the system shaped more and more precisely according to the requirements and the experiences of the people using it, so the effectiveness of a team-work would be expressed at its best.

THE FRONT-END ARCHITECTURE

In our approach the Front-End architecture is the innovative software infrastructure for supporting collaborative work of the human operators of the team involved in the disaster scenario discussed in the previous section. Each team member is equipped with mobile devices (e.g. PDAs) and s/he is in connection with the other team members in a P2P MANET network. The organization of the peers of the Front-End in a MANET is very important in emergency scenarios in which each device has to communicate directly with the peers in its radio range without a physical infrastructure that may be no more available in an emergency situation. In this way the devices can build a complex communication and computation infrastructure over which they can run the collaborative applications to support the operators/teams in their operations.

In our running example the members of our specific team are equipped with PDAs and with the specific software able to remotely invoke functions of the GIS engine running on the Back-End organization supporting the team, in order to monitor the evolution of volcanic eruption on the basis of *(i)* geo-information collected in "peace time" and *(ii)* functions implemented remotely by the GIS engine.

Figure 3 shows the visualization and the invocation of the remote functionalities through a PDA.

In the designed architecture the team member, which is in-charge of the management of the geo-information, is able to locate and to invoke through a simple browser the services the Back-End GRASS engine is able to implement. In particular in our example the team operator needs (and invokes) the function of the GRASS engine that is able to predict the run-time evolution of the lava flow on the basis of information about the slope of the volcano collected in peace time or the wind velocity collected during the emergency (Figure 3.b and 3.c). In our approach the GIS functionalities are deployed as WSs on the application engine of the Back-End and they are presented to the team members through a Web page.

Through the WS the team member receives the GML file containing both the geo-information (including the run-time information of the lava flow useful in our example) and the graphical-information (the geometrical properties) that characterize the map of the involved area. In order to correctly visualize the information the operator needs, we have provided the PDA with the software to translate the geo-information retrieved from the GML file into a SVG file that is an XML-based file containing information that the usual browsers are able to translate in the concrete image allowing the visualization of the area the team member is interested in.

In deeper details the software on the PDA has to *(i)* parse the GML file, *(ii)* retrieve all the geo-information needed and *(iii)* translate it in graphical elements in the SGV representation.

The last operation can be done online in a pure client-server fashion, for example embedding suitable Java Script code in the Web page used by the Back-End to present the map to the team member. In this case the team member PDA is a real thin client and it needs only a browser with suitable plugins.

The novelty of our approach consists in the possibility for the team members to apply modifications to the maps they receive, to update them with new information related to the emergency situation (e.g., an interrupted road); in order to achieve this aim we have realized a client-side application residing on the PDA of the operators, that after the invocation of a remote functionality (e.g. visualize the maps of the volcano surroundings) through a suitable WS deployed on the Back-End, *(i)* receives and parses the GML file and *(ii)* using suitable Java classes translates the GML information in SGV format for the visualization.

When a team member wants to realize modifications of the map, selects the point on the map in which the change occurred and modifies it inserting a comment, then the application translates the graphical modifications in GML code and sends them to the other peers of the MANET. The other team members receive a pop-up notification of the occurred modification and update the map through the same operations described above. The team leader receives the modifications too, and if the they are "tagged" as definitive (i.e., they are supposed to last for more than few hours) then s/he communicates it to the Back-End. Such modifications are used to update the Geospatial DB of the Back-End and a new map of the zone is created and presented to all the teams involved in the emergency scenario, to other Back-End systems and to other Geodata providers. If the modifications are temporary, then the new modified map is sent directly to the team members that need it for their tasks and to the Back-End that stores it in a temporary folder without any definitive update of the system.

The integration of P2P technology and the use of the described location-aware mobile devices let us achieve important results consisting in the possibility for a team member with a client without much computational power or disk/storage space, to fully access GIS functionalities (that require the consumption of many resources) thus lowering the barriers to the exchange of geo-information.

THE USER INTERFACE

This section presents the functionalities and the actual usage of the user interface of our GIS module at Front-End.

When an emergency fires, the team members make the request for the map of the area they are interested in sending to the organizations at Back-End their position (obtained through GPS) and specifying the dimension of the required map (Figure 3.a). Now each team member has the availability of the map of the affected area, and s/he can overview all the important aspects to face the emergency. For instance, in the case of the imminent volcano eruption, s/he should know the current position of the habitations and the streets disposed around the volcano, potentially at risk to be flooded by the magma (Figure 3.b).

As shown in Figure 3.b, these functions are invoked selecting the menu "Show Layers", that presents a list of all the available features that can be represented on the map. Moreover, the interface allows to display the current position of the team members as well as the territory geomorphology or other geo-information.

The real innovation carried out by our GIS system is the possibility to realize remotely a high level geo-analysis and to build simulations of how a disaster could evolve. In the example of the volcano, an important information consists in the path of the magma after the eruption. This particular function is performed by "MagFlow" (Figure 3.c), a tool developed for GRASS, able to simulate the flow of the magma of a specific volcano. When the operator selects "MagFlow" and clicks *Start*, the WS exporting that specific functionality of the GIS engine is invoked. The tool produces a simulation on the operator's map (Figure 3.d), allowing her/him to know the possible path of the magma and the time spends to reach a particular point of the map. These kinds of information are useful for the team leader, who can decide the priority in the evacuation of the habitations or in the closure of the streets.

Figure 3.e and 3.f shows the operations enacted by the team member to send notifications to other operators (or to the Back-End system): s/he clicks on a critical point of the map (e.g., a closed road), s/he insert a comment, and the notification is sent to other members to facilitate their operations.

Figure 3. The User Interface

CONCLUSIONS AND FUTURE WORK

In this paper, we proposed an architecture that subsumes a Back-End part which provides geo-information services to a Front-End part. The Front-End is represented by a team that in an emergency scenario can invoke the services in order to run environmental and urbanistic evaluations. In particular in the paper we address the problem of the execution of complex GIS functionalities (requiring great resource consumption) by thin client (i.e., devices without computational power and storage). We achieve the result by deploying and exposing the GIS services on a Back-End application service through WS technology. This work is the basis of the development of a GIS-oriented Back-End inside the WORKPAD project we are currently involved in.

We plan to move towards an even more decentralized approach, by transferring selected functionalities of our Back-End system onto the mobile devices constituting a MANET. From this, we expect beneficial system behaviour such as the reduction of risks of system and service unavailability.

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