Emergency Management: from User Requirements to a Flexible P2P Architecture

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ABSTRACT

The most effective way to design an emergency management system matching user needs is to perform a User-Centered Design; it relies on continuous interactions with end-users in order to understand better and better how organizations are arranged during emergencies, which data are exchanged and which steps are performed by organizations to face disastrous events. In this paper we *(i)* illustrate the methodology used to collect the user requirements for the emergency management system developed in the European research project WORKPAD, and *(ii)* describe the WORKPAD high level architecture stemming from such requirements. Specifically, the methodology is applied in the context of Regional Civil Protection of Calabria (Italy) and is used as basis to provide more general user requirements for emergency management systems.

Keywords

User-Centered Design, Requirement collection, Civil Protection, Emergency Scenarios, Peer-to-Peer Architecture

INTRODUCTION

Disaster is a broad term; it can be defined as a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources (Zerger, 2003). The term "emergency management" means the coordinated activities both to prevent disaster happenings and to face them when they take place.

The emergency management activities can be grouped into five phases (GIS for Emergency Management, 2005). Specifically, we focus on *response* and *short-term recovery* phases. When a disaster happens, the response phase is designed to provide emergency assistance for victims. It also aims at stabilizing the situation and reducing the probability of secondary damage and at speeding recovery actions. The recovery activities aim at returning the living conditions to normal conditions and they usually include two sets of activities. Short-term recovery activities return vital life-support systems to a minimum operating standard. These phases are actually the most critical, and are the focus of the recently funded European project WORKPAD (http://www.workpad-project.eu).

In order to devise successful ICMT (Information, Communication & Media Technology) architectures for emergency management, we advocate the use of user-centered techniques, according to the Human-Computer Interaction paradigms (Dix et al., 2003). User-centered design relies on a continuous interaction with end-users through questionnaires and interviews. They are intended to understand better and better how organizations are arranged during disastrous happenings, how and which information is exchanged among teams and with their respective operational centers. The more designers will be able to go into the "mind" of actors, the more the system

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will match user needs and be appreciated by users. If designers devise systems without continually taking into account user impressions and needs, those systems are going to fail since they will not be used by real actors. With respect to other methodologies used in previous research projects about emergency management, the main contribution of our work is a careful use of all possible techniques to get feedback from users such as interviews, scenarios and task analysis. (Dix et al., 2003). This requires a continuous contact with final users, by leading them not only to answer to simple questions, but also to think about their suggestions and impressions.

Section 2 introduces the methodology we used to collect user needs, which will be also used in the next rounds of user requirements collection. Section 3 shows its application in the specific context of Regional Civil Protection of Calabria (Italy). In Section 4 we try to go further the specific context in which we applied our methodology, in order to provide general user requirements for emergency management systems.

Starting from collected user requirements and their generalization, we designed the WORKPAD architecture. Such an architecture is based on a 2-levels peer-to-peer (P2P) paradigm: the first P2P level is for the front-end and the latter level is for the back-end. The need of such two P2P levels arises from the analysis of user requirements, as widely described in Section 3: there exist back-end central halls where the chiefs of involved organizations are located, as well as several front-end teams which are sent to the affected area. The control room and the chief of an involved organization represent a peer of the back-end level; in turn each peer, if separately considered, is a complete 3-layer system which has one presentation layer, one middle layer for coordination and one data layer for data integration and exchange. The same is at the front-end level: team members should be equipped with special devices (PDAs, smartphones, etc.), and each team should be arranged in a P2P Mobile Ad-Hoc Network (MANET) for intra-team coordination and communication. In turn, each team is supported by the back-end level which provides the proper information for tasks performance and inter-team coordination. We give more details about the architecture in Section 5. The existence of two different P2P levels is a novelty over other relevant research projects working in the area of emergency management, such as SHARE (`http://www.share-project.org`), FORMIDABLE, EGERIS (`http://www.egeris.org`) and ORCHESTRA (`http://www.eu-orchestra.org`), which does not perform this distinction.

Finally, Section 6 concludes the paper by summarizing future work.

A METHODOLOGY FOR COLLECTING USER REQUIREMENTS

When a new system is created, the first step that the development team has to perform is the definition of user requirements. Once identified, user requirements effectively lay the foundation for developers, testers and implementers to begin determining the functionalities, responsiveness and interoperability required by the system (Courage and Baxter, 2004). The methodology used for the user's requirements collection and analysis within the WORKPAD project is shown in Figure 1.

It starts with personal *interviews* of the potential users and possible workshops which gives an opportunity for requirements engineers to better understand the tasks of the users. Interviewing is a guided conversation that involves structured or unstructured discussion between engineers and potential users of the system; this is the most frequently used technique. This phase results in a clear definition of the user groups and in an overview of the current working situation, responsibilities and tasks of the potential users. In the next phase, the engineers and potential users work close on the development of *scenarios*. Scenario building is an inexpensive and quick method for the collection of requirements and tasks information, and allows users to create a context for their requirements and tasks. It enables the potential users to be more creative and to identify requirements and tasks that other methods may not surface. An advantage of this method is that it does not provide any prioritization of requirements and tasks. We got scenarios through *storytelling*: users describe situations through stories. Stories are described in a "free-text style"; there is no formalization, e.g., structure of the processes, required in this phase.

The most important result from scenarios is a deeper understanding of the differences among several users' groups and their basic workflows performed within the organizations (Caroll and Rosson, 1992; Denning 2001). These scenarios serve as basis for the specification of functional requirements and task analysis. *Task analysis* aims at showing an overall structure of the main user tasks; it includes the overall users' responsibilities in processes, goals to achieve and tasks which users intend to perform to achieve goals. A possible approach, known as "Hierarchical Task Analysis" (HTA) (Dix et al., 2003), divides high level tasks into their constituent subtasks which, in turn, are further subdivided up to a given level of detail. A task can be defined as a goal combined with some ordered set of actions. The task decomposition process is better represented as a tree, since tree represents naturally hierarchical concepts without any kind of precedence. It comes often with a plan to give a possible order of sub-tasks.

HTA must be independent from the application, the planned system, or other techniques used to perform the main tasks. So, it is easy to allocate tasks into whichever application, and it enables easily to develop a conceptual model for them.

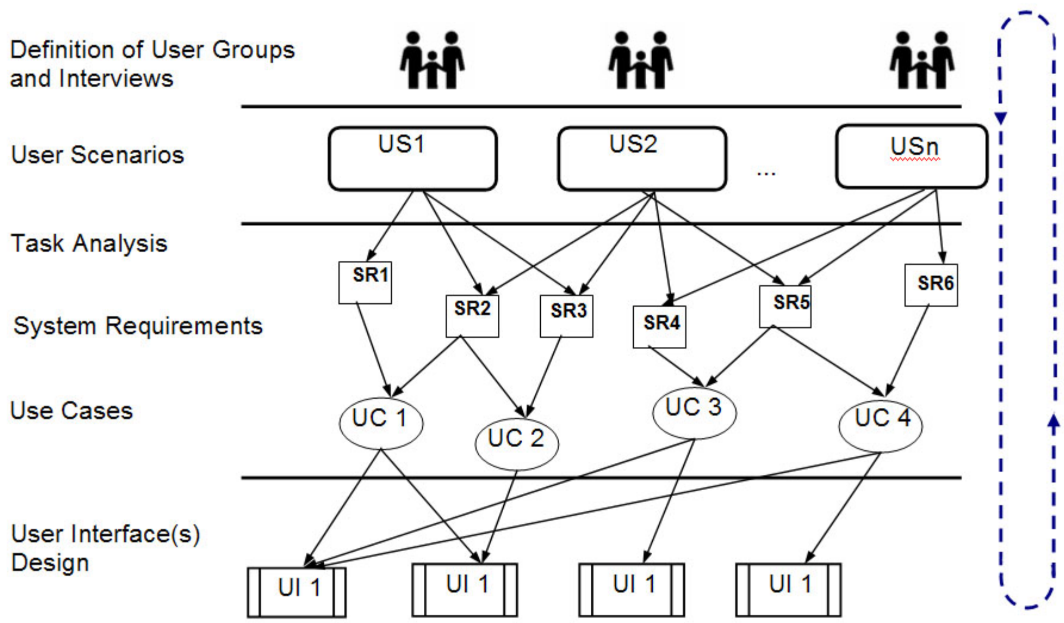


Figure 1. The WORKPAD methodology for the user requirements analysis

Scenarios and task analysis give the needed input for the *users requirements analysis*. Users requirements allow to define *(i)* problems each user meet performing his task, *(ii)* solutions he has in mind to solve problems and *(iii)* users' real needs (that is the functionalities which systems, both computer-based and not, have to provide). In general, starting from users requirements, it is possible to distinguish between functional and non-functional system requirements. Functional requirements identify the characteristics and requirements posed on the target applications/systems, whereas non-functional requirements specify global constraints on how the software operates or how the functionalities are exhibited. Once functional requirements (what the system should do) are described in form of use cases, non-functional requirements (how the system should work; how fast, how efficiently, how safely, etc.) can be added.

USER REQUIREMENTS' COLLECTION FOR THE CALABRIA'S CIVIL PROTECTION

In order to collect user requirements for the WORKPAD project and to understand how Civil Protection works during emergency management, we interviewed officers and generic actors of the most important organizations involved in emergency management. In collaboration with the Civil Protection of Calabria (an Italian Region), we identified two typologies of users: *back-end* and *front-end users*. Front-end users are all the operators acting directly on the field during disasters (ranging from firemen to voluntary associations). Back-end users are all the operators who manage the situation from control rooms, by providing goals/instructions/information to front-end operators. We used a set of open-ended questions, allowing each interviewee to answer to any question as he/she prefers. In such a way, we asked several questions according to user's typology and activities.

The interviews were divided in two parts: a first, more general, and a second one, depending on the category which the user belonged to. This means that two versions of the second part exist: one for potential front-end users and another one for back-end users. The main purpose of the interviews was to identify the user and his/her activities in the context of a disaster, since the moments just after the disaster to the moments during she/he are acting. We asked them to imagine a realistic situation that could happen during their work and to describe the tasks to face it (cfr. the adopted storytelling technique).

Organizational Requirements of Civil Protection Department in Calabria During Emergency Management

The response to disasters is regulated in Italy by the Law 225 (24 February 1992): it organizes the Civil Protection as a national service, politically coordinated by the premier. It consists of central and local authorities, and includes public corps and private institutions existing in the national territory.

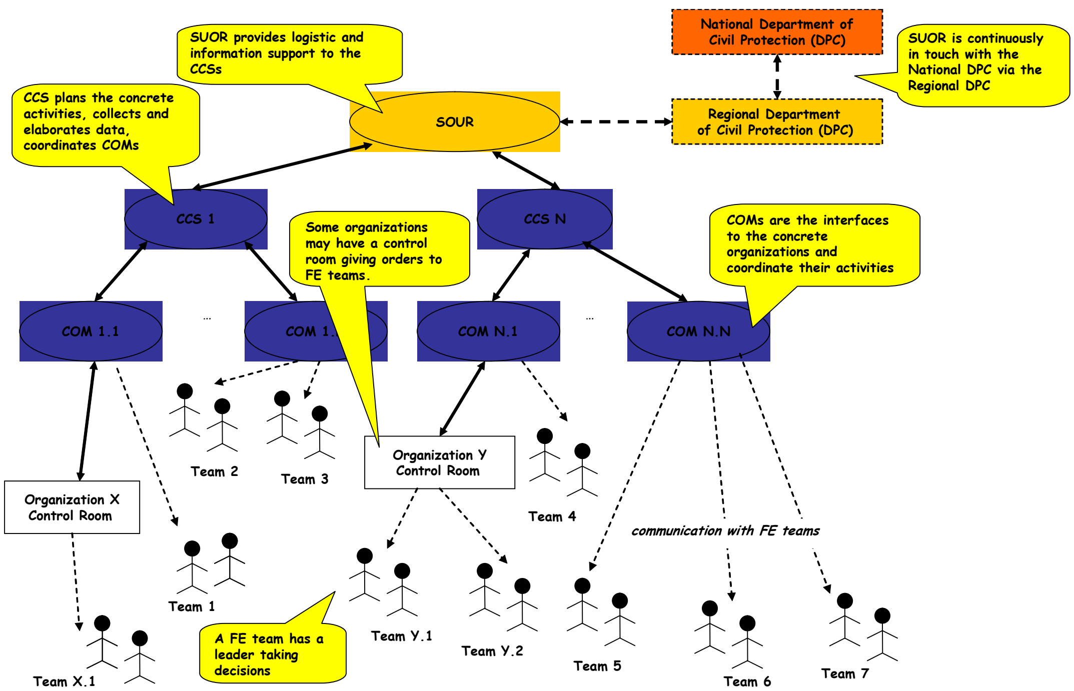


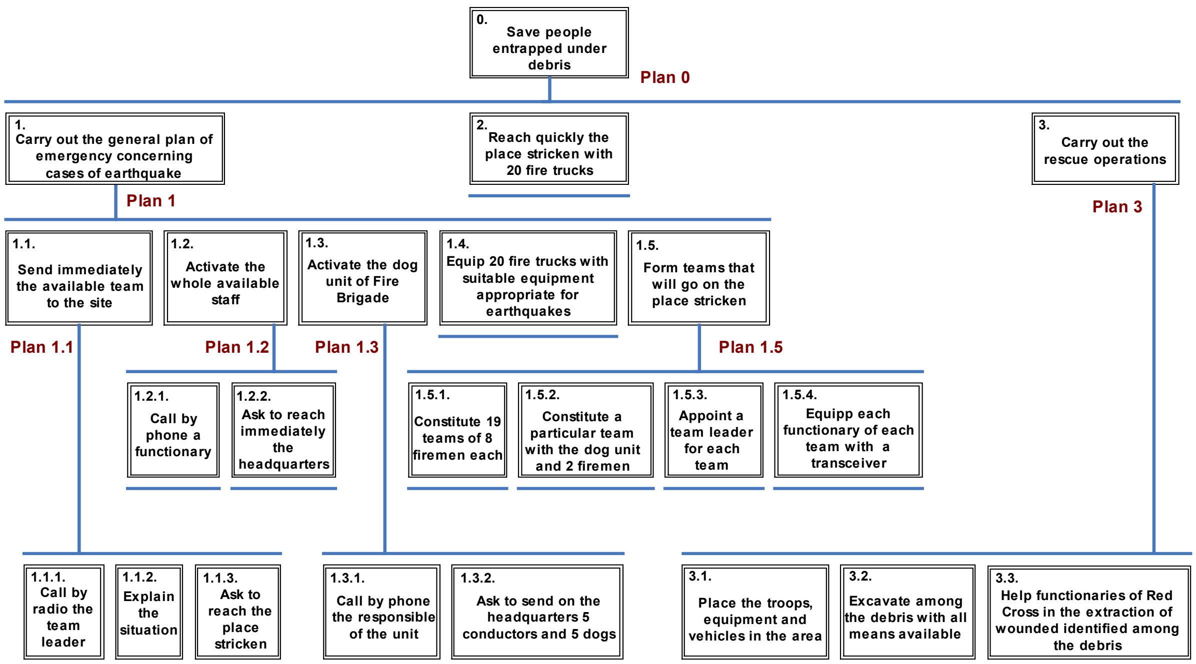
Figure 2. Overview of the Italian emergency management hierarchy

Specifically, the "Augustus method", strictly linked to the Law 225, describes how to plan during disasters and clearly delineates a method for response activities. It gives guidelines and general procedures to effectively coordinate Civil Protection activities. To cope unpredictability in disaster occurrence, adaptive strategies have been devised by the Italian Civil Protection (Galanti, 2004), based on the observation that – as the Emperor Augustus used to say – "the value of a plan decreases as the complexity of the situation grows". Such strategies are meant to provide a suitable approach to the problem of coordinating complex operations according to flexible plans in disaster contexts.

At regional level, the Civil Protection Department in Calabria has the availability of an operational control hall, called SUOR – Sala Unificata Operativa Regionale [Regional Unified Room for Operations]. Here, two persons permanently (i.e., 24 hours/day) monitor the situation. Usually, SUORs are equipped with basic infrastructures to get information and to communicate: fax server systems, radio communication systems, hydrometeorological monitoring control systems, etc. The SUOR's activities are focused to control possible alerts, e.g., from the hydrometeorological system, to receive, to check and to manage any kind of event and to issue alert messages. SUOR is continually in touch with the national Civil Protection Department and, when a calamitous event happens, with the prefectures in the Room areas, in order to furnish them a logistic and informative support.

When a disaster breaks out, the actual coordination of required activities is in charge of the Province (Calabria consists of five provinces: Catanzaro, Cosenza, Crotone, Reggio Calabria and Vibo Valentia). These tasks include the activation of the CCS – Centro Coordinamento Soccorsi [Centre for Coordination of Aids], which represents the strategic-operational top line of the Civil Protection at this level (one CCS exists in each province). CCS is coordinated by the Prefect and is composed by a fixed number of officers of the organizations (Police, Fire Brigade, etc.) which need to be always involved in emergency management (according to the Augustus method). Moreover, according to the specific disaster, CCS can be integrated by officers of other organizations, whose competences can be useful to face the specific situation; e.g., ANAS [National Agency for the Road Network] is involved in scenarios where roads have to be restored. Main CCS tasks are inspections, the collection and elaboration of data and information concerning the evolving situation, the continuous connection with SUOR and the coordination of all activities performed by COMs.

A COM – Centro Operativo Misto [Mixed Operational Center] is an operative decentralized structure depending on the CCS. Each province can have more COMs arranged in its area, e.g., the province of Reggio Calabria has 19 COMs. A COM is closer to the disaster: it acknowledges immediately the different local demands and organizes the work to be carried out. COMs should return any result to CCS, as CCS has to get a complete and updated scenario and can coordinate the work of several COMs. Figure 2 shows the summary of the actual organizational structure.



Plan 0 : Do 1 and then 2. Upon arriving of fire trucks, do 3.
Plan 1 : Do 1.1; then do 1.2, 1.3, 1.4 contemporaneously. Afterwards, do 1.5.
Plan 1.1 : Do 1.1.1, then 1.1.2 and finally 1.1.3.
Plan 1.2 : Repeat 1.2.1 followed by 1.2.2 while all available functionaries are alerted to reach headquarters.
Plan 1.3 : Do 1.3.1, then 1.3.2.
Plan 1.5 : Do 1.5.1, 1.5.2 in an arbitrary order. Then do 1.5.3, 1.5.4 in an arbitrary order.
Plan 3 : Do 3.1; then do 3.2, 3.3 contemporaneously.

Figure 3. Task Analysis and execution plan

Nowadays, communications between operating structures (front-end teams, COMs, CCSs) take place by telephone and/or fax. This is a first critical point, as it allows only personal one-to-one communication without using any analytical or graphical tool, e.g., GISs (Geographical Information Systems). The organizations (Fire Brigades, Police, etc.) in COMs communicate with their respective control rooms, through radio frequencies or, if unavailable, by telephone and fax. For some organizations, control rooms might not exist, and therefore COMs communicate directly with front-end teams. Usually, each control room has a computer system where data and information concerning the disaster are collected and stored. Nowadays this information is not directly shared with any other organization. At front-end, usually each team has a leader that takes decisions; inside a team, communications typically are performed by transceivers and mobile phones. Moreover it is not possible to communicate directly with members of other organizations: all the inter-team coordination is at the back-end level, where possibly officers have got more data and information which are helpful to make choices.

An Example

This situation described in Section 3.1 is very high-level and illustrates the general arrangement of the organizations during an emergency management. The actual work which organizations perform depends strongly on the disaster characteristics. In order to go deeply into "the mind" of rescue operators, we asked them to illustrate their own personal experiences in past-occurred disasters. We have called them storyboards, since they describe a specific situations to be faced, taking into consideration some relevant conditions. Figure 3 shows the decomposition of the task "Rescue Entrapped People" (cfr. HTA) in a storyboard about the Fire Brigade's intervention after the collapse of two building: the purpose is to save people entrapped into the rabbles. It is important to underline that task analysis does not focus on cognitive processes of the users executing tasks, but only on the strategy as a sequence of steps in order to reach the goal. So, it observes user behaviors: *what* they do to perform tasks without considering the reasons (the *why*).

GENERALIZATION OF THE USER REQUIREMENTS

Starting from specific user requirements collected in Calabria, we have tried to go over that specific context in order to get needs which are more generally valid. Abstracting over specific contexts is a critical but important challenge, since systems, which are built according to such general needs, can be used in a wider range of applications. A synthesis of the performed analysis is as follows:

[1] *ICMT support for back-end teams (i.e., control rooms) and front-end teams (i.e., rescue teams on the affected areas).* Currently the technologies adopted are mainly personal voice/paper communication technologies (phone, fax) and no automation in the exchange of data and information is available. Such a support should be different for front-end teams and for back-end centers, as the first ones are more involved in the effective executions of actions, whereas the back-end centers are more concerned with integration of data and information (in order to take appropriate decisions and to coordinate different teams).

- *(a) Activity coordination support for the front-end.* Front-end teams would benefice of automatic support to the coordination and execution of their activities.
- *(b) Integration of data and information for the back-end.* Back-end centers would benefice of on-the-fly integrating data and information collected and stored by other involved organizations. This implies interoperability among possible back-end information systems. On-the-fly integration is needed as the effective organizations taking part in the management depend on the disaster itself, and therefore no fixed a-priori integration system can be built, but it should be set-up dynamically on a disaster-basis.

[2] *Reliable communications between front-end and back-end teams*. Currently the link between front-end and back-end is based on radio links (for mobile phones or transceivers). Besides the fact that such media is not completely reliable, in a possible future scenario in which also relevant data and information are sent through such a link, its reliability and bandwidth become critical.

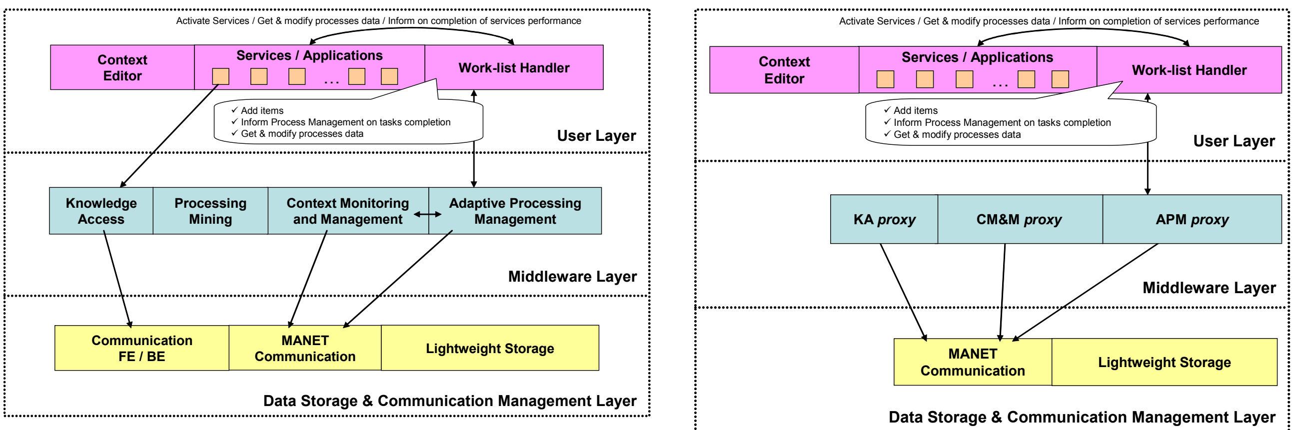
[3] *Smart hand-held devices for front-end teams*. The most effective way – as of our knowledge – for realizing requirement [1](a) is to provide smart devices to front-end operators, and to have a coordination system running on them. Clearly usability of such devices (and the important aspect that they should not distract operators in their main rescue activities) is critical.

- (a) *Working also in disconnected mode.* Devices are not continuously connected with the back-end. Therefore, applications for the front-end teams should be completely residing on the front-end teams, and when the link with the back-end is available (hopefully most of the time, as of requirement [2]), they can "synchronize".

[4] *Access and collection of geo-information about the affected area.* Operators would benefice of the availability of geo-information about the affected area. As an example, they could get installed on their smart devices a GIS application, and by "touching" the map on the screen getting data about the area.
Moreover, geo-data should be collected by front-end actors and sent to back-end centers, for possible integration with other information. Geo-data should not be collected by "paper and pencil" and vocally

communicated to back-end by phone (as currently happens), since that action could distort them, conversely front-end operator should be enabled to insert data by themselves directly into the system.
Finally, suitable data models should be investigated. Indeed data models presented in the form of a map are not always usable by the users in an emergency situation. Alternative data models are based on landmarks combined with selected context needed for the specific use case. The concept of a landmark is central: the landmarks are seen as points of reference, or, more focused, as features that are relatively better known and define the location of other points (Presson and Montello 1998).

[5] *Organizational peer-to-peer.* As discussed, the organizational structure of the Civil Protection is hierarchical, but the number of different levels that are involved is not fixed, and may vary from disaster to disaster (how many CCSs, how many COMs, how many organizational control rooms – and no all organizations have control rooms, etc.). Moreover, an analysis over other European countries shows that the organizational structure is different from country to country. Therefore the best way to accommodate such an organizational heterogeneity is to devise a peer-to-peer organizational system, in which each *potential* structure that may take part in emergency management is equipped with an instance of the system (i.e., the peer) and during the set-up of the specific configuration for a given disaster, connections among the peers are established in order to reproduce the hierarchy for that situation.



(a) Coordinator Peer *(b) Generic Peer*

Figure 4. Front-end Architecture

THE PROPOSED ARCHITECTURE

Starting from requirements collected in Calabria and generalized in Section 4, we have devised for WORKPAD an architecture which consists of one back-end level for control rooms and one front-end level for teams sent to the affected area. Each of two level is a peer-to-peer (P2P) system.

The WORKPAD front-end level is made up of several teams. The members of each team belong to the same organization and are equipped with mobile devices (e.g., PDAs or laptops) (cfr. requirement [3]). Team members establish a P2P Mobile Ad-hoc NETwork (MANET) for coordination and intra-team communication. A MANET is a P2P network of mobile nodes capable to communicate with each other without an underlying infrastructure. Nodes can communicate with their own neighbours (i.e. nodes in radio-range) directly by wireless links. Non-neighbour nodes can communicate by using other intermediate nodes as relays which forward packets toward destinations. Every node has to keep and update routing tables to know usable paths to forward data packets to destinations. The lack of a fixed infrastructure makes this kind of network suitable in emergency management scenarios where it is needed to quickly deploy a network but the presence of access points is not guaranteed (cfr. requirement [3](a)). As well, since the available bandwidth (roughly 11 Mbps) is enough, MANETs can guarantee a good QoS level.

The WORKPAD back-end includes a set of *knowledge peer*s (roughly one peer for each organization). Knowledge peers integrate their data, content and knowledge which are gathered and used for emergency managements. They form a P2P community that provides advanced services running on servers with high computational power. Such an integration is by standard interfaces (cfr. requirement [1](b) and [5]). In order to guarantee a quick activation of involved organization, back-end should provide reliable publish/subscribe mechanisms for alarms dissemination.

As far as communication of front-end teams with back-end, TETRA seems to be a good choice. TErrestrial Trunked RAdio (TETRA) is an ETSI standard to build specialist Professional Mobile Networks. The low frequency which TETRA uses allows very high levels of geographic coverage; indeed TETRA is specifically intended for Police Fire Brigades, Army, etc., and its relays are generally arranged so that, even if some of them go down, the others can cover most of the area. That does not hold in other technologies. The main disadvantage is a low data transfer rate which makes difficult to transfer and exchange great deal of data via TETRA links. But this is not an issue, as front-end teams internally use wireless links (cfr. MANETs) and they should revert to TETRA only *(i)* when they need to access to the back-end and *(ii)* if other technologies (e.g., UMTS) are not available (cfr. requirement [2] and [3](a)). P25 is a standard used in North America for similar purposes, even if P25 equipment is considerably more expensive than TETRA.

Figure 4 zooms in the front-end architecture and modules which composes it. We assume the team leader (named coordinator in the figure) to be equipped with a laptop where generic nodes may be simple PDAs. That enables it to coordinate team members in addition to perform actual tasks . Such modules can be classified in three layers:

- **Data Storage & Communication Layer.** It includes the *MANET Communication* module implementing MANET multi-hop communication and *Lightweight storages* for data and knowledge storing (in a local or distributed fashion). Current operating systems do not allow communication among non-neighboring wireless peers, so a specific software module which implements one (or more) of existing MANET algorithms is needed. Some implementation already exists, such as (Chakeres et al., 2004) and (De Rosa et al., 2003). The coordinator device, in addition, holds a further module named *Communication Front-end/Back-end* to handle connections with back-end (by means of UMTS, etc. and switching to TETRA when needed).
- **Middleware Layer**. The core element of the front-end middleware is the *Adaptive Process Management*. It is used to adaptively control processes to be conducted during emergency managements. It supports workflow execution (cfr. requirement [1](a)). It could be based on existing prototypes, such as MOBIDIS (de Leoni et al., 2006) or $WASA_2$ (Weske, 2001). This component has to manage processes in an adaptive manner on the basis of contextual information retrieved by *Context Monitoring and Management*. Contextual information provided will be associated with devices and networks, human profiles and activities, emergencies scenarios, etc. It includes also geo-data and information retrieved from back-end and updated by the front-end teams (cfr. requirement [4]). The component *Knowledge access* includes a set of libraries that simplify the access of user applications to back-end knowledge peers. A component for *Process Mining* is provided; indeed its aim is to detect workflows patterns, social behavior of individual members and whole teams and possible correlations (Dustdar, 2006). The Middleware Layer at generic nodes are really simpler, as it consists only of specific modules whose purpose is interacting with coordinator counterparts. As required, all the front-end system is deployed on the MANET, in order to be able to run also in disconnected mode and/or requiring low bandwidth for accessing – when needed – to the back end.
- **User Layers**. Our idea about users' interaction follows: whenever the process manager assigns tasks to actors, it inserts them in their *Work-list Handlers*. Users learn assigned tasks by querying this list. When users are ready to perform a given task, they pick the corresponding item in the work-list, together with data needed for its execution. The handler knows which skill (service) is required to its execution. According to the required service, handler runs the corresponding application to provide the service. When the application is closed, possible modified data comes back to handler with task completion signaling. Handler forwards data and such a signal to process manager. Moreover, there exists the separate component *Context Editor* allowing to enter additional contextual information which could not be captured by front-end middleware. Specific services offered by the devices are deployed in the basis of the capabilities and skills of the corresponding team member.

CONCLUSIONS

In this paper, we have presented a 2-level architecture for emergency management in the context of project WORKPAD. The idea of two levels, one for front-end teams and another for back-end general headquarters of involved organization is a novelty, since other prototypes and projects does not perform this distinction. Such an architecture comes from a careful analysis of requirements of the end-user partner of WORKPAD. We collected such requirements by applying a user-centered design, which relies on continuous interaction with end-users by questionnaires, interviews and other techniques. To the best of our knowledge, this is the first project trying to perform methodically that and it should guarantee the system will be consistent with users needs.

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