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Selecting Computing Devices to Support Mobile Collaboration

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Abstract

Collaboration supported by mobile devices has brought advantages for users and also challenges for software developers and mobile computing devices manufacturers. Every kind of device used to support mobile collaboration has strengths and weaknesses depending on the work context where it is used. The idea is to use a specific device when advantages are most relevant and disadvantages do not affect team work. This paper proposes an evaluation framework that helps developers to identify the type of device that can be used to support mobile collaboration in specific work contexts. In addition, three mobile collaborative applications are analyzed using the evaluation framework. The results of the analysis are then compared with the empirically observed suitability.

1. Introduction

Many people need to be on the move to accomplish their jobs. That work could be carried out in a plane, bus, subway or just walking. Mobile computing devices such as laptops, PDAs and smart phones could be convenient to support such activities. The capabilities of these devices have pushed the frontiers of the Computer-Supported Cooperative Work (CSCW) area including mobile collaboration scenarios. Mobile collaboration is focused on processes and tools that allow users to collaborate using mobile devices. Although many articles describe mobile collaborative applications (Antunes and Costa 2002; Kirda *et al.* 2002; Pica and Sorensen 2004; Häkkilä and Mäntyjärvi 2005), it is not obvious when a specific type of mobile computing device is the best choice to support collaboration. On the other hand, it is clear the work context is relevant when we have to make a device selection decision.

Häkkilä and Mäntyjärvi defined the work context in mobile collaborative scenarios as the set of "contextual attributes related to environmental factors, user's activity and user's goals" (Häkkilä and Mäntyjärvi 2005). The mobile collaboration process can typically involve several work contexts related to phases of the whole process or users' roles. Identifying the most appropriate device to support collaboration in every work context involved in the collaboration process is a highly important part of the solution design. Researchers have identified key elements of the work context that can be used to determine when a type of mobile computing device can be used to assist collaboration (see Anckar and D'Incau 2002; Divitini *et al.* 2004; Pica and Sorensen 2004; Häkkilä and Mäntyjärvi 2005). However, these key elements (i.e., battery life, screen size and data input) could be relevant in various degrees for each work context. Therefore, the relevance of the key elements should be considered during the analysis of possible computing devices to support mobile collaboration.

This paper presents an *evaluation framework* that collects and organizes general work context elements and relevant device features in order to allow the identification of most advantageous computing devices to support mobile collaboration in each work context. This framework may be useful for developers of mobile collaborative applications. Various implementations may have to be built perhaps involving more than one type of computing device to be used in the work contexts (e.g., a collaborative application to run on a notebook, and another one to run on a PDA).

The framework definition and organization was based on the study of three mobile collaborative applications previously developed. The method employed to create the framework was based on the proposal of Roberts and Johnson (1996) it suggests to start developing at least three different applications. After these developments, it is possible to characterize common elements of the framework. The initial definition of the framework evolved based on the theoretical findings of other researchers in the area. The evaluation framework was applied to the three studied applications and the results were compared with the empirical observation.

A similar framework has been proposed by Anckar and D'Incau (2002), but it is focused on m-commerce. Such framework is "useful for assessing whether, and in what ways, a specific service/application is likely to offer added value to consumers over a wireless medium". The most relevant differences between the Anckar's framework and the authors' framework are the following:

- The authors' framework evaluates computing devices to support collaboration. By contrast, the Anckar's framework evaluates mobile services to support m-commerce.
- The authors' framework considers several work contexts in order to carry out the evaluation. It is not clear what work contexts are considered in the Anckar's framework. Anckar and D'Incau talk about what they consider "wireless support"; this seems to imply "stable wireless communication".
- The authors' framework has clear processes to apply it and to analyze the results. In the case of the Anckar's framework it is not clear how to apply it, what are the results, and how to interpret such results.

The rest of the paper is organized as follows: Section 2 analyzes the relation between the work context and the requirements of a collaborative solution. Based on a literature review, Section 3 presents the strengths and weaknesses of mobile computing devices to support collaboration. Section 4 presents the evaluation framework and the strategy followed to define it. Sections 5 to 7 present the three mobile collaborative applications used as a basis to develop the evaluation framework. Section 8 discusses the results obtained when the evaluation framework was used to analyze the collaboration processes involved in the three presented applications. Finally, section 9 presents the conclusions and future work.

2. Work Contexts and Requirements of the Solution

There are specific definitions of work context for various work scenarios (Dey and Abowd 2000). Thus, Häkkilä and Mäntyjärvi defined the work context in mobile collaborative scenarios as composed of contextual attributes related to environmental factors, user's activity and user's goals (Häkkilä and Mäntyjärvi 2005). The environmental context elements are physical factors that can influence the collaboration process, such as noise, light, available physical space to work, and networking services availability. The attributes related to the user's activity involve issues such as: level of data input required to do it, use of multimedia information, mobility level to be supported and type of interaction to be supported. Finally, the attributes related to the user's goals include issues such as deadlines or the dynamic nature of such goals. Typically the users' goals contribute to the common goal of the collaboration process.

The work context of a collaboration process is usually dynamic and it involves several specific work contexts (Figure 1) (Alarcón *et al.* 2005). Each specific work context is related to one or more users' activities that are part of the collaboration process. Various in-depth

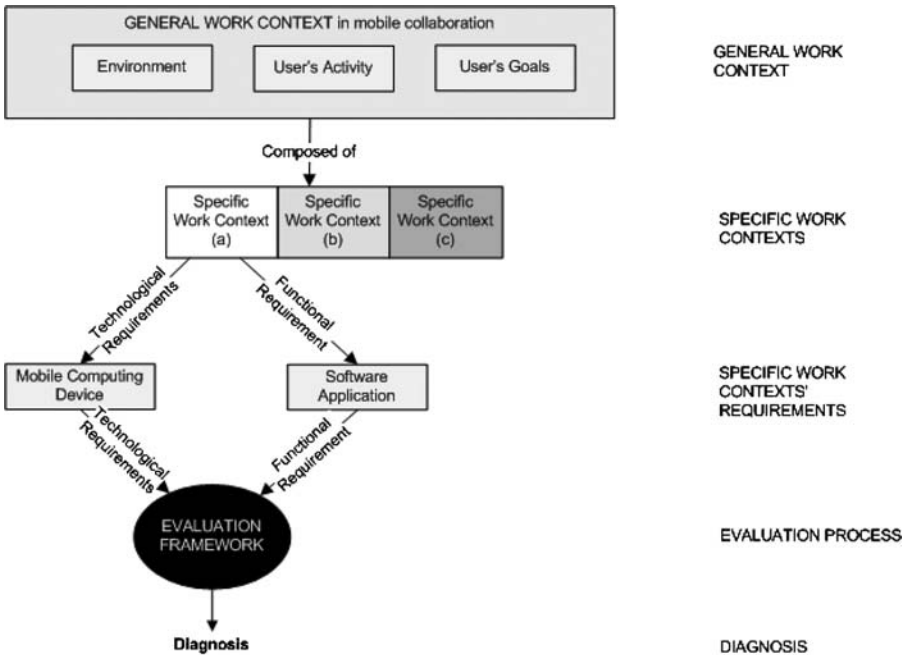


Figure 1. Relation between the evaluation framework and the work context.

studies have shown how apparently separately working people collaborate intermittently in a very subtle way (Cockburn and Thimbleby 1991; Heath and Lupp 1992). Hence, although collaborative work generally refers to situations where two or more people act together explicitly to achieve a common goal, the actual extent of "togetherness" can substantially vary. Designers of collaboration technology should therefore take into account the fact that collaborative processes could be represented as combinations of individual and collaborative activities involving several work contexts.

For example, let us assume that a group of researchers need a tool to support collaborative text authoring. Researchers want to be able to work on shared text documents asynchronously at their offices and also on the move (e.g. subway or bus) using local replicas. In addition, they want to insert comments into these documents. The contents of replicas (including the comments) will be synchronized during a synchronous co-located working session in order to make group decisions on conflicting updates. The unique role to be supported by the solution is the co-author, who is also able to include comments to a document. Analyzing the collaboration process it is possible to identify synchronous activities (e.g. replicas distribution and synchronizations) and asynchronous activities (e.g. text authoring and commenting). Synchronous and asynchronous activities can be done at the office or on the move. A preliminary analysis of users' activities and work environments to be supported indicates that at least there are three different work contexts to be considered by the groupware solution (Figure 1): (a) asynchronous text authoring/reviewing in the office, (b) asynchronous text authoring/reviewing on the move, and (c) documents synchronization and distribution. Developers should choose the most suitable devices to support the corresponding activities based on the analysis of the three work contexts. This decision has implications on the software to be developed and thus, this is one of the factors to be considered in the decision process. This occurs because a software piece is not usable on all device types, and therefore, some software pieces may have to be created to provide similar functionality with various computing devices.

Each specific work context provides requirements that should be addressed by computing devices and the software application to be used. Particularly the environmental factors (e.g., uncomfortable workspace) and the features of the users' activity (e.g., massive data input) provide *technological requirements* to be satisfied by the computing devices to be used. On the other hand, the features of the users' activity and the users' goals (e.g. fast reviewing of a whole document), which are part of the same specific work context, provides *functional requirements* to the software application supporting the activity. The proposed evaluation framework acts as an instrument allowing mobile groupware applications developers to match technological requirements with functional ones in order to determine: (a) advantages and disadvantages of every type of mobile computing device to support the application functionality in such work context, (b) which variants of a software application need to be developed in order to cover the specific work contexts, and (c) what functionality could be included in each variant.

Based on a literature review, next section describes general capabilities and limitations of computing devices focusing on those that can be used to support mobile collaboration. These issues will be useful to identify computing devices able to address functional and technological requirements provided by a specific working scenario.

3. Capabilities and Limitations Reported in the Literature

Mobile computing devices have various capabilities and limitations to assist mobile collaboration, depending on the device type: notebooks, tablet PCs, PDAs and mobile phones. The type of notebooks, tablet PCs and PDAs considered are representative of the latest devices available in the market. The tablet PCs considered are devices able to be used with keyboard, mouse and pointing devices. In the case of mobile phones, recent versions of these devices (smart phones) are considered, which include operating systems such as Windows Mobile 2003 or Symbian OS v6.x/7.x.

Next two sections present a literature review on capabilities and limitations of these mobile computing devices. These issues where used as a validation instance for the evaluation framework. Then, Section 3.3 presents a literature review on added value services provided by mobile computing devices.

3.1. Requirements from the collaboration environment

The collaboration environment includes features from the physical scenario (e.g. buildings and streets), the physical activity the user is doing while collaborating using the device (e.g. walking, driving or being seated) and the current environmental conditions (e.g. level of light/noise and number of people moving around). Weather conditions seem to provide similar limitations for any type of mobile computing device, thus they are not considered. These environmental features can impose requirements on the mobile computing devices used to support mobile collaboration. Next, we present the key issues reported in the literature.

3.1.1. Users' mobility

Users' mobility on a physical environment depends on the features of the physical environment where the users are located and the current environmental conditions. A user equipped with a mobile computing device can be *traveling*, *wandering* and *visiting* (Kristoffersen and Ljungberg 2000). Traveling is defined as the process of going from one place to another in a vehicle. Wandering, in turn, refers to a form of extensive local mobility where an individual may spend considerable time walking around. Finally, visiting refers to stopping at some location and spending time there, before moving on to another location. Sarker and Wells report that "the optimal size of a device associated with wandering was necessarily lower than an acceptable device size when visiting or traveling" (Sarker and Wells 2003). In that case, PDAs and mobile phones may be most appropriate to support wandering, since the smaller the device size the more mobility the user may have. However, the device size reduction implies restrictions at least on the screen size and input capability (Kortuem *et al.* 2001). On a first analysis, tablet PCs can also be used to assist wandering. When we consider devices appropriate to support visiting and traveling, notebooks and tablet PCs seem better than handheld devices, because of their features to support stationary work (B'Far 2004). Nevertheless, handheld devices are easy to transport and thus, they may have an advantage in that respect. Mobile phones are useful to support communication among collaborators in the three mobility scenarios.

3.1.2. User's safety
If the physical environment where the user is located is safe (e.g. a waiting room), there are no restrictions to the use of any type of mobile computing device from this viewpoint. On the contrary, if the physical environment is unsafe or potentially dangerous (e.g. a disaster area), handheld devices are more appropriate than notebooks or tablet PCs (Tarasewich 2003). This is because handheld devices are easy to deploy and carry, and also they require low user's attention and have short start-up time. These features allow fast reaction from the users; such speed could be critically needed in these physical environments.

3.1.3. Communication support
The communication support available in the user's environment conditions the type of device he/she is able to use in mobile collaboration activities. Mobile phones are not appropriate when communication support is not available in the user's environment. However, mobile devices with Wi-Fi communication capabilities are able to form a MANET (Mobile Ad-hoc NETwork) (Kortuem *et al.* 2001) to support collaboration in scenarios without networking services available (such as in disaster areas) (Aldunate *et al.* 2005). We understand "one-hop communication" as wireless, and "multi-hop communication" as mobile (e.g. MANETs) (Tschudin *et al.* 2003). On the other hand, the type of mobility to be supported influences the type of work the user is able to do. Typically, wandering involves short and simple interactions between the user and the system (Kortuem *et al.* 2001); thus just basic communication support is required (network availability and bandwidth). By contrast, large bandwidth is usually required when traveling or visiting, because the user is able to carry out long and complex interactions through the system (Sarker and Wells 2003).

3.1.4. Current environmental conditions
The environmental conditions include features such as level of light/noise, weather conditions and number of people moving around (Tarasewich 2003). It also includes the dynamics of these environmental conditions. Considering these key elements, handheld devices are better than notebooks/tablet PCs in every adverse and dynamic environment because they are easy to deploy, interconnect and involve a short start-up time. Furthermore, their size and the possibility to use them with few fingers provide them additional advantages in crowded, disturbing or dark environments (Aldunate *et al.* 2005).

3.2. Requirements from the mobile collaborative applications

Mobile collaborative applications have specific requirements to support the functionality required by every user's role involved in the collaboration process. Next, key issues reported in the literature are presented.

3.2.1. Data input
A possible requirement for a mobile collaborative application is the need for massive data entry. PDAs and mobile phones use pen-based data input, which is slow, but also useful to support short annotations (Buyukkokten *et al.* 2000; Sarker and Wells 2003). On the other

hand, notebooks and tablet PCs are the most appropriate devices to support data intensive processes using the keyboard. The input process of other data types, such as image, video or audio, is operatively similar for any kind of mobile computing device. However, the features of each device limit the quality and quantity of data that is able to capture and store.

3.2.2. Screen size

Screen size requirements are related to the amount of information the user needs to comprehensively see to support the corresponding activity. Applications with large visual representations require large screens such as notebooks' screens. Although handheld devices have been criticized in the literature by their small screens (Guerrero *et al.* 2004; Kortuem *et al.* 2001), recent visualization techniques have improved the capabilities of these devices to display graphical/detailed information (Baudisch *et al.* 2004).

3.2.3. Privacy

Computing mobile devices usually have small screens, and thus, they provide better privacy protection than notebooks and tablet PCs if data displayed on screen needs to be hidden from other people in public spaces. Furthermore, the physical distance between the user and the handheld device during the interactions is shorter than the distance between a user and his/her notebook or tablet PC. Another privacy consideration in mobile collaboration is the visibility of the users and users' actions in MANETs or public networks (Kortuem *et al.* 2002). Ensuring accuracy of location information and users' identities, and establishing private communication could be a critical issue in some cases (Chen and Kotz 2000).

3.2.4. Storage and memory capacity

System design restrictions because of storage and memory reasons have been reported in the literature, especially related to handheld devices (Kortuem *et al.* 2002). However, this type of mobile devices keeps improving their storage and memory capacities. Last versions of these devices allow mobile applications to manage and store complex data types, even simple multimedia information. If the network bandwidth is stable and wide, then the storage and memory capacity of these devices becomes even less important, because the devices can do buffering. Considering this issue, the most limited device to support mobile collaborative applications today is the mobile phone.

3.2.5. Processing power

Like storage and memory requirements, the processing power needed for certain mobile applications can exceed what handheld devices can currently offer (Kortuem *et al.* 2001; Guerrero *et al.* 2004). However, in case of PDAs, it is possible to find commercial devices with CPU speeds higher than 500 Mhz. The processing power limitation of these devices becomes visible, e.g., while processing multimedia information. Although every mobile computing device is able to address basic multimedia needs, just notebooks and tablet PCs are able to handle strong multimedia requirements, such as support for 3D games.

3.2.6. Communication capabilities

Mobile collaborative applications require synchronous/asynchronous communication capabilities depending on the activity to be supported. If asynchronous communication is required, every mobile computing machine is able to provide such support based on minimal network availability. On the other hand, if synchronous communication is required, a permanent and stable communication service should be provided independently of the environment the user is located (Sarker and Wells 2003). Mobile phones supported by cellular networks are typically the best option for synchronous communication provided their large coverage range and good signal stability (Malladi and Agrawal 2002). However, these networks have a limited bandwidth. Another option is to provide synchronous communication capabilities to mobile applications using a Wi-Fi communication infrastructure (Roth and Claus Unger 2001; Kortuem *et al.* 2001). Although the bandwidth is better than cellular networks, Wi-Fi signal stability depends on the physical environment where it is deployed (Aldunate *et al.* 2005). Furthermore, this type of networks has a limited coverage range (Malladi and Agrawal 2002).

3.2.7. Activity duration

Activity duration in mobile collaboration could be limited by battery life. Many researchers have identified this issue as critical to support mobile collaboration (Kortuem *et al.* 2001; Guerrero *et al.* 2004). However, the use of context-information provides a way to optimize the use of power supply resulting in a longer lasting battery life (Chen and Kotz 2000; Häkkilä and Mäntyjärvi 2005). On the other hand, it is always possible to carry extra batteries when PDAs, notebooks or Tablet PCs are used. Activity duration is not so critical in the case of mobile phones because these devices are able to work for many hours without being re-charged (Häkkilä and Mäntyjärvi 2005).

3.3. Value-added services of mobile computing devices

Researchers in mobile collaboration have identified several settings in which mobile computing devices can create value. Some relevant situations are the following ones:

3.3.1. Time-critical arrangements

Time-critical situations could arise from external events, which are communicated to the user through push-technology solutions (Anckar and D'Incau 2002). An example may be an alarm sending warning messages to a user, who receives it in his/her device. However, it implies the mobile computing device should be in a state allowing it to receive the messages. Mobile phones are advantageous to support these applications.

3.3.2. Spontaneous decisions and needs

Individuals may request services at any time without an external stimulus (Anckar and D'Incau 2002). These services may be related to purchases, entertainment needs or social interaction.

3.3.3. Entertainment needs
Mobile applications fulfill the need for killing time/having fun in situations where there is no access to wired entertainment applications (Anckar and D'Incau 2002). PDAs are advantageous in this situation because they are easy to deploy in almost any scenario and they have short start time.

3.3.4. Efficiency ambitions
Time-pressured users are able to use the dead spots in the day effectively. Mobile computing devices provide them the capability to increase their productivity based on the work away from office during such periods (Anckar and D'Incau 2002; Sarker and Wells 2003).

3.3.5. Mobile situations
These are situations where services are of value only through a mobile device, as the need for these services predominantly arises while away from home. Anckar and D'Incau mention localization services (e.g. routing) and roadside services (e.g. vending/parking machine payments) as examples of these services (Anckar and D'Incau 2002). In addition, Sarker mentions that mobile devices add value when the user is wandering, visiting and traveling (Sarker and Wells 2003). Mobile situations involve simple or medium-complex interactions between a user and a system. Typically PDAs and mobile phones are useful to support simple interventions (such as checking email and reading/sending short messages) and notebooks and tablet PCs are appropriate for medium-complex interventions (e.g. text authoring) (Guerrero *et al.* 2004).

3.3.6. Anytime-anywhere accessibility needs
Anytime/anywhere accessibility has obvious advantages because it makes users reachable and it also allows them to use remote resources (Sarker and Wells 2003). However, it requires permanently available networking services between interacting devices. Although anytime-anywhere accessibility is still ambitious, mobile phones and Wi-Fi networks scope is increasing.

3.3.7. Communication and data sharing in MANETs
Mobile computing devices sharing a communication standard - such as Wi-Fi or Bluetooth - are typically able to self-organize to make up a MANET (Mobile Ad-hoc NETwork). This network can provide communication support to devices that are moving inside the MANET coverage area. The MANET is then used for messages interchange and data sharing among people located in environments lacking communication infrastructure, such as a disaster area (Malladi and Agrawal 2002; Aldunate *et al.* 2005).

3.3.8. Work in uncomfortable places
Mobile computing devices can also add value in work contexts involving uncomfortable places, e.g. crowded or unsafe environments (Tarasewich 2003; Aldunate *et al.* 2005). These devices allow users to move around in order to find a place with acceptable comfort conditions. In these scenarios, handheld devices are better than notebooks/tablet PCs because they are easy to deploy and interconnect and they involve a short start-up time.

4. The Evaluation Framework

The initial framework has been defined based on the method proposed by Roberts and Johnson (1996). Their proposal was intended for evolutionary frameworks development in any specific problem domain. The first step in this method consists of developing at least three applications in the subject area. These developments will be useful to make abstractions from the concrete instances. The framework is not complete immediately thereafter, since it is expected the framework will evolve with time. However, the salient features of the framework can then be obtained. Once the applications are built, it is possible to characterize use scenarios as well as to prescribe recommendations for the development of new applications in this problem domain.

The proposed framework has been designed based on the three applications described in sections 5 to 7. The main framework goal is to provide a diagnosis on the types of mobile computing devices that are suitable to support mobile collaborative activities. The mobile computing devices considered are notebooks, Tablet PCs, PDAs and mobile phones. The most recent versions of computing devices were considered for the evaluation framework as mentioned above. The framework also qualifies desktop PCs not just for completeness, but also to show these computing devices are similar to notebooks and Tablet PCs considering many features. It means that many collaborative applications developed for desktop PCs could be used in notebooks and Tablet PCs when the communication service in the user's environment is similar to the service provided by wired networks. Mobile phones, on the other hand, include several PDA features. The tendency towards the integration of these two types of devices shows that in the near term they will probably have the same capabilities to support collaborative work.

The framework considers mainly the set of requirements from the collaborative activity to be supported and the user's collaboration environment. Based on these requirements and their relevance level, the framework identifies advantages and disadvantages of any type of mobile computing machine to support a mobile collaboration activity. This information allows developers to identify strengths and weaknesses of the collaborative solutions running on the various kinds of devices.

4.1. Relevant issues

Based on the analysis of the developed applications and their use as tools that support mobile collaboration processes, the following set of issues were identified as relevant when we have to select a mobile computing device to support collaboration: *data input capabilities, external device support, multimedia support, memory storage capacity, complex user interface capabilities, storage capacity, processing power, screen size, data persistency capabilities, unplugged power supply, MANET capabilities, device wearability, work while walking, uncomfortable places use* and *start-up time*. The first seven issues have been explained in Section 3.2 and the next seven ones were presented in Section 3.1.

Table 1 rates mobile computing devices based on the previously mentioned issues. The rating for each cell was assigned based on the consensus of six experienced users on these

Table 1. Machine features to support collaborative applications.

	Desktop PC	Notebook	Tablet PC	PDA	Mobile Phone
Data input capabilities	+++	+++	+++	− −	− − −
Multimedia support	+++	+++	+++	+	−
Memory storage (volatile) capacity	+++	+++	+++	+	−
Storage capacity	+++	+++	+++	+	− −
Processing power	+++	+++	+++	+	− − −
Screen size	+++	+++	+++	+	−
Unplugged power supply	− − −	++	++	+	++
Work while being transported (traveling or visiting)	− − −	+++	+++	++	++
MANET capabilities	− − −	+++	+++	+++	−
Device wearability (easy to move)	− − −	+	+	+++	+++
Work while walking (wandering) capabilities	− − −	− −	++	+++	++
Uncomfortable places use	− − −	−	+	+++	+++
Start-up time	− − −	− − −	− − −	+++	++

+++, very appropriate; ++ appropriate; + acceptable; − unsatisfactory; − − deficient − − − inappropriate.

machines. This table is inspired by the Software Quality Function Deployment (SQFD) table (McDonald 1995). In the case of the first issue of Table 1 (data input capabilities), the rates were defined based on the use of the following input devices: PDAs and mobile phone using a pointing device; notebooks and desktop PCs employing keyboard and mouse (or equivalent device); and Tablet PCs employing keyboard, mouse and pointing device (light pen).

The ratings shown in Table 1 disadvantageously compare PDAs and mobile phones with desktop PCs, notebooks and tablet PCs in terms of adequacy to handle complex user interfaces, capacity to store large amounts of information, multimedia support, screen size, external devices support and facilities for data input. By contrast, handheld machines are better suited than the other computers to support work in uncomfortable places or in terms of wearability. Tablet PCs have features in common with both notebooks and PDAs and thus they may be adequate to support work in cases where the other types of machines are not suitable or have drawbacks.

4.2. Using the framework

It is possible to identify the best mobile computing device to support collaborative activity in context by considering the requirements from each specific work context. The first step is to identify which of the features listed in Table 1 are present in the specific work context. Second, such features should be ordered by priority. Then, Table 1 will help to determine the strengths and weaknesses of each type of computing machine to support the work context requirements. If a certain type of device is clearly identified as the best one, then it is clear that a software application should be designed and implemented for such device. However, this is not a typical situation. Usually, two or more devices appear as possible solutions by showing strengths and weaknesses to address different work context requirements. In such a case an option is to choose only one device to support more than one specific work context of the collaborative solution. This solution saves developers the need to develop several versions of the collaborative application.

Another way to choose a computing machine is by eliminating low priority requirements until a machine clearly appear as the best. This strategy works when none of the high level requirement becomes eliminated. A mix of the two presented strategies can also be used to identify the mobile computing device for a specific work context.

Next sections describe the three mobile collaborative applications used as a basis to develop the evaluation framework. Section 5 presents a case of text co-authoring activity. A second case – supporting disaster relief efforts – is described in Section 6, whereas Section 7 includes the case of supporting dramatic production processes.

5. Text Co-authoring

We were asked to develop a system intended to support a group of scientific researchers trying to write a joint technical paper. Scientific papers are an important method of publication (Schulman 1988; Sharples *et al.* 1993). A scientific paper is written for the scientific community at large. The contents may be, e.g., a survey, a tutorial, a presentation of a theoretical model or a discussion about new experimental results. The typical paper needs to introduce the subject, place any results within the context of other scientific works, and suggest future possibilities for research.

Some roles need to be specified, e.g., scribe, reviewer, coordinator. Also, some goals achievement strategies and social protocols are required. In our case, we were told not all co-authors would be co-located at all times. Furthermore, some co-authors wanted to work in certain specific locations, such as at an airport lounge while waiting for a plane, or in the plane itself. One future user of the system even mentioned he would like to try to work in the subway while returning home at evening. Since there was eventual work on the move, this was a case where PDAs might be useful. However, we needed further elements to characterize the work context.

Prospective authors had in mind to divide the initial writing task among some of them. Each of these writers would produce a draft of a part of the article. After finishing this divergent task, they would have a meeting for information sharing and synchronization. During or after the meeting, some co-authors want to be able to review and re-write material. A new iteration of divergent/convergent work may then occur until, at some meeting, all authors agree the latest version of the article fulfills their expectations.

The situation resembles the example we mentioned in Section 2. We have three specific work contexts for this case:

(i) co-authors work asynchronously from their offices doing parallel work,
(ii) some co-authors do some asynchronous work from remote places, either in a fixed location (e.g., airport lounge), or being transported (e.g., plane, subway train),
(iii) co-authors do some synchronous/co-located work during the face-to-face meetings in an office.

It is clear the best devices to support the work contexts (i) and (iii) would be desktop PCs or notebooks (and Tablet PCs used as notebooks) considering the work is not going to be on the move, there is a need for normal screen size, and there is much input to be entered to the system. If the local files are relevant to carry out the collaborative activity, the notebooks will provide a better support than desktop PCs. In addition, notebooks running the same application used in (i) and (iii) are able to address the requirements of the work context (ii). However, a notebook would not be appropriate to support work in a crowded subway train. Is it important to do such work in this case? What specific kind of activity could be done while standing in a train trip anyway? We asked these questions to the future users.

The users said they could work with the notebook solution, but they would prefer to be able to eventually work on a train. The kind of work in a train would mainly be to produce annotations and to make corrections to previously stored text.

5.1. Designing the solution

Based on the previous analysis, the collaborative application called MoSCoW (Mobile Support for Collaborative Writing) (Inostroza 2003) was implemented in two variants; for desktop PCs/notebooks and PDAs. The application for desktop PCs/notebooks was used to support text and multimedia authoring and editing in (i) and (iii), and also in the work context (ii) but just running on notebooks. The application for PDAs was limited to text editing and commenting in (ii). It was assumed a wireless LAN and Internet connection are available for (i) and (iii). Users, however, may ignore the mobile support if they decide to do their work in a more conventional way for a certain writing project, using only desktop PCs or notebooks.

Let us consider first the support when using PDAs in the work context (ii). The design of this variant of the system included the possibilities of working network-connected or off-line. When working network-connected, the user works in a way resembling workstation use, i.e., document synchronization is automatic. Off-line PDA work occurs when the co-author steps outside the range of the wireless network. In this latter case, the PDA stores a "copy" of the original document; the co-author then does all text editing as desired. Of course, after off-line work, the performed changes must be synchronized with the master document. When this is done, the master document is stored as a new version. In turn, this means all stored versions must be merged (synchronized) at some time. A coordinator must do this merging, and usually this involves discussion with the other co-authors in order to keep document coherence.

Figure 2 shows a diagram of a collaborative text-editing job supported by PDAs and desktop PCs/notebooks. Represented activities are editing from a desktop PC or notebook,

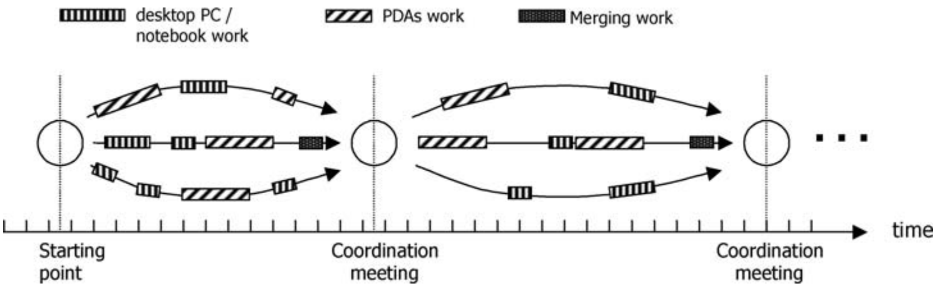


Figure 2. A sample of an activities sequence.

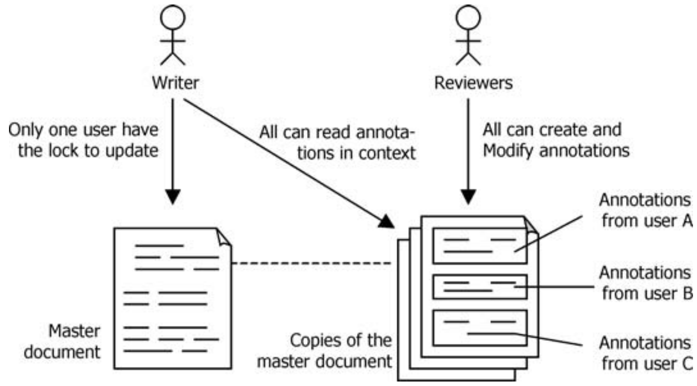


Figure 3. Concurrent work on a document.

editing from PDAs, and merging processes. Large nodes represent coordination meetings. The three depicted co-authors, represented through the sequences, may do divergent work in the most convenient way according to their needs. We may guess that perhaps many of the contributions generated from PDAs are annotations or brief statements which are developed in full when working from workstations afterwards. A single co-author with the coordinator role is responsible for merging the various existing versions (see Figure 2). This latter type of task must be done with the other co-authors being aware and agreeing.

It should be noted the merging process is only needed to incorporate changes made from off-line PDAs or notebooks because the synchronous work considers on-line update of shared documents. Concurrent access to shared documents is managed using a locking mechanism that assures only one user is able to update a shared document, and the others users have just reading access (see Figure 3). Annotations, however, may be done concurrently with one user doing updates on the master document, and they are visible by all group members. However, annotations are actually made on a copy of the master document.

The software system consists of three modules, which allow static or mobile operation: *Web editing module, PDA editing module* and *communication module*. Next, each one of them is presented.

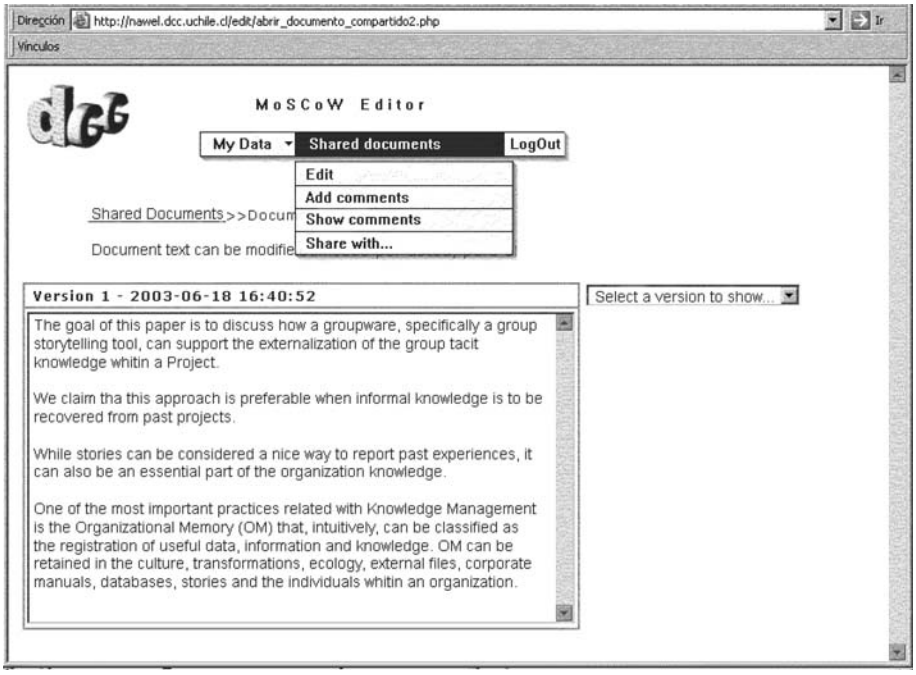


Figure 4. Editing a document from a Web browser.

5.2. Web editing module

The web editing module is an application that runs on desktop/tablet PCs and notebooks, and lets users to create, edit and share documents through the Web. When a group member creates a new document, he/she must provide the list of co-authors and the roles assigned to each of them (the current implementation just considers *reader* and *reader/writer*). A co-author can modify a document by first locking it; after making changes, he/she must unlock it. This module also lets co-authors to generate a new document version. Furthermore, the same module allows co-authors to add own annotations and see annotations provided by other users. Figure 4 shows a document being edited via Web.

5.3. PDA editing module

The PDA editing module is a variant of the Web editing module presented in the previous section. Although the Web and PDA editing modules are similar, the PDA module is compact, it has a simple user interface and it uses little storage. Despite this austere design, the PDA module is able to provide the main functionality of the Web module.

Figure 5 depicts the navigation model of the PDA editing component. Entrance to the system is done through the main page. Here, basic data for connection to the server is

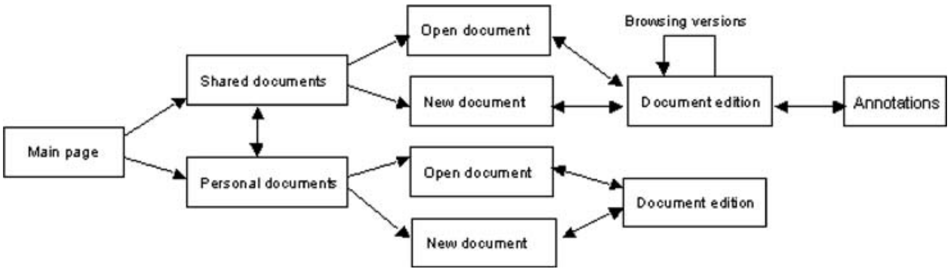


Figure 5. Navigation model for the PDA editing module.

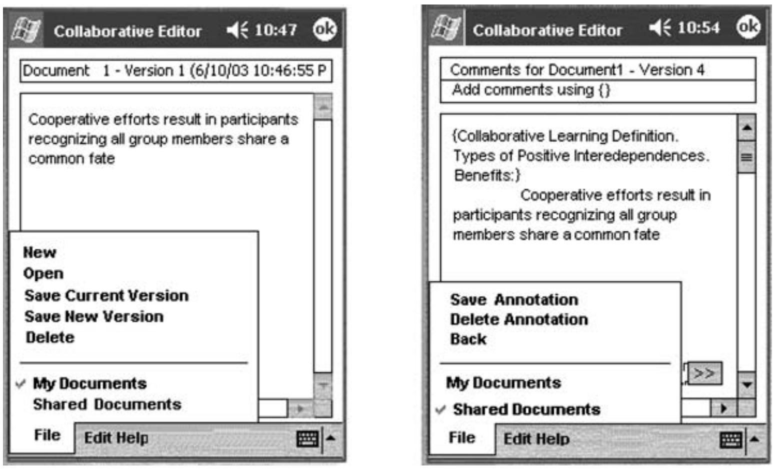


Figure 6. (a) PDA editing module user interface and (b) adding annotations.

initialized. Then, a choice must be made by the user: work on shared documents or personal ones. Shared documents will be the normal choice; personal documents will not be shared when the PDA will get synchronized with the server.

The co-author may create new documents or open previous ones. These may be personal or shared. A typical use may be to create a personal document with an outline of ideas; these are expanded later in a shared document. Shared documents may have several versions, which can be navigated by the co-author. The user can also place annotations on any document from this software module.

Figures 6a and 6b show the PDA editing module user interface. The upper part of the screen has information on the current document. The middle part of the screen presents the document, and the lower part contains the application menu. Figure 6a shows the "File" menu options. The editing menu has an option to work on the various versions: buttons allow moving forward or backwards on the local document versions.

Annotations can be added to personal or shared documents. In the case of shared documents, a co-author is permitted to include annotations only if he/she has the corresponding privileges. Annotations creation privileges also include permits to delete them. Annotations are entered as text comments enclosed within braces (Figure 6b).

5.4. Communication and synchronization module

This module allows communication and synchronization between PDAs and the server database. The database is also accessed by the Web editing modules. The main difficulty solved by the communication module concerns concurrency, since several co-authors could be editing the same document at the same time. The module also solves the document versions management problem. Keys for a simple solution to these problems are the locking mechanism already mentioned and a time stamp associated by the system to each document version. Time stamps are then used by the system itself to guide co-authors on which versions are appropriate for merging.

The locking mechanism is paired with a unique version of the document, called the master document, as introduced above. When a co-author has blocked the master document, the other co-authors can make annotations over copies of the master document. At a later time, a co-author can modify the master document based on his/her colleagues' annotations. For such task, the system lets visualize all document copies associated to a master document as separate windows (Figure 7). Annotations are shown in color to make them easily distinguishable.

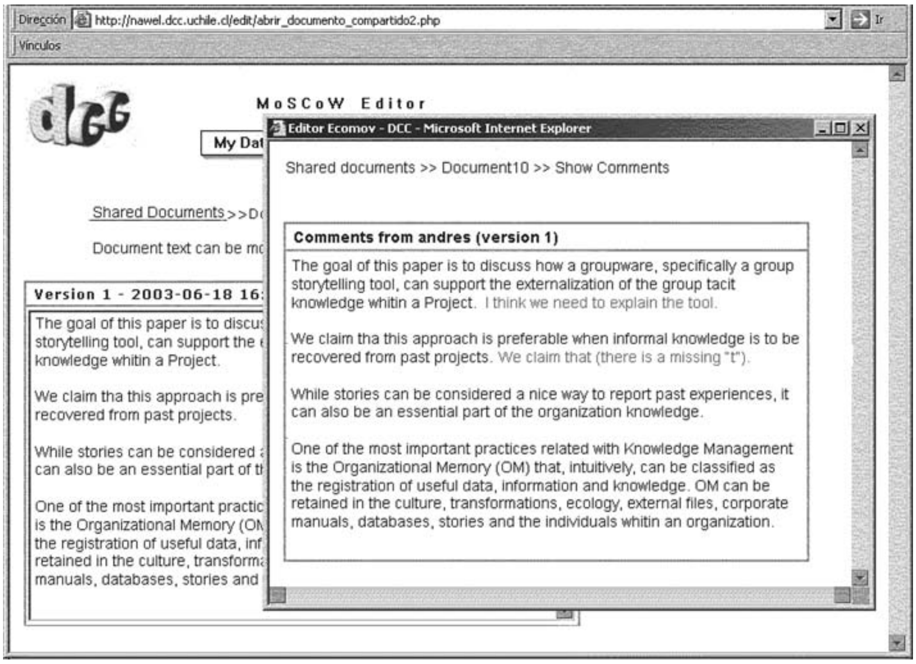


Figure 7. Improving the master document with a copy containing annotations.

6. Collaborative Support to Disaster Relief Efforts

Activities to resist and recover from natural, hazardous and intentional eXtreme Events (XE), such as terrorist attacks, chemical spills, hurricanes and earthquakes, should be quick and effective (Mileti 1999). Every disaster work context is different; however they share a chaotic, unstable, stressful and dangerous environment. In such situations, activities for resisting and recovering from an XE demands effective collaboration among a broad range of organizations, agencies and entities with diverse missions, which work together in order to reduce the impact of the XE on society (Comfort *et al.* 2004; National Science and Technology Council 2003). This collaboration is needed because each entity is specialized to solve a part of the problem and the mitigation process requires more than the addition of the parts (Leith 1999; Stewart and Bostrom 2002).

The collaboration process in disaster work contexts requires *communication* and *coordination* but allowing high mobility of first responders. In addition, this process should also be quick and effective because the situation becomes worse as time passes. These requirements impose important restrictions to groupware system and mobile devices used to support collaboration among first responders.

Typically, in major disasters the mitigation efforts involve participants at three levels as depicted in Figure 8. The participants at the support level are people (e.g. experts or government authorities) and organizations (e.g. hospitals, civil organizations, meteorological center and center specialized in disasters) which provide services to the management level in order to help mitigate a disaster. Eventually participants at this level collaborate among them in order to provide an improved or comprehensive set of services.

On the other hand, the management level usually includes few police officers, firefighters, medical personnel and federal agencies personnel that are in charge of managing the mitigation process. They are the command post and are located close to the disaster area. These people need to collaborate mainly to generate solutions, to make decisions and to coordinate the groups involved in the first response and recovery processes. Frequently, the obtained results of these processes depend on the quality of the collaboration process.

Finally, the participants at the fieldwork level are usually firefighters, police officers, medical personnel and Government personnel executing orders from the management level. They collaborate to carry out the physical tasks and to receive/give feedback about the evolution of the disaster and the mitigation processes.

The collaboration environment for people in support and management levels is safer and more comfortable than the collaboration environment for people doing fieldwork. In addition, the mobility of these people is low or null and the probability of having communication infrastructure is high. However, the work context for people in the fieldwork level is different from this. The participants should have high mobility because the characteristics of the physical environment (unstable and dangerous) and the nature of the task they should carry out (search and rescue or infrastructure stability evaluation). These people need communication and information support in order to collaborate with other first responders and with the people at the command post.

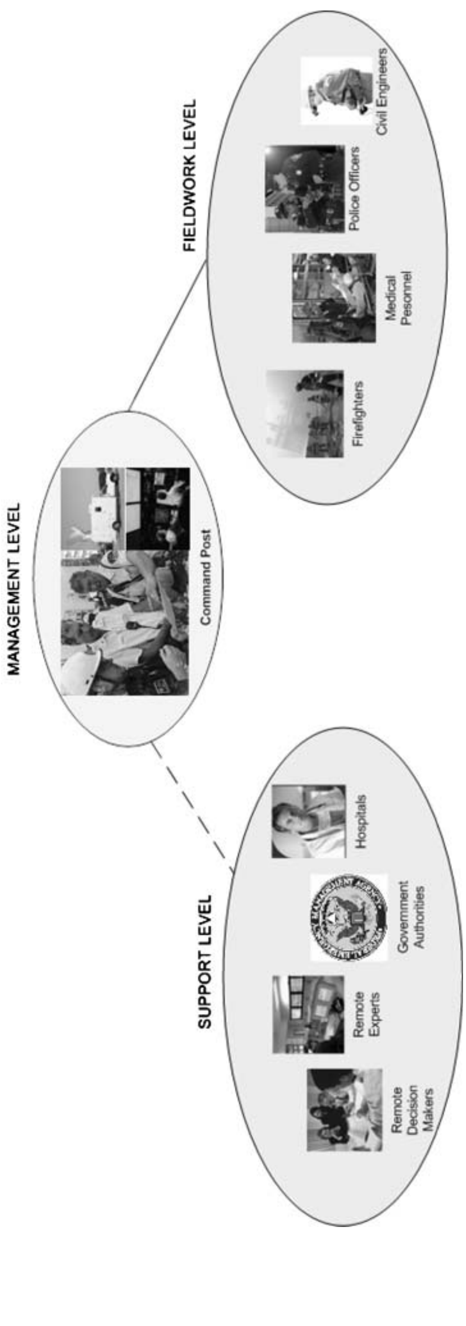


Figure 8. Structure of the collaboration process during disaster relief efforts.

In summary, in disaster relief situations at least two specific work contexts should be considered to support: (i) the collaborative work done by people in the support and management level, whom will use desktop PCs and notebooks, and (ii) the collaborative work done by people in the fieldwork, whom will use PDAs or mobile phones. Next two sub-sections describe the design and implementation of the groupware system variants, developed to support collaboration in these two specific work contexts.

6.1. Design of the groupware system

The groupware system developed to support the collaboration process in disaster work contexts was called CoSDRE (Collaboration Support for Disaster Relief Efforts). The system is a kind of collaborative GIS (Geographic Information Systems), which also provides collaboration support between the command post (management level) and remote experts (support level), and also between the command post and the first responders working inside the disaster area (fieldwork level).

People located at the command post have usually low mobility and can work in a comfortable place, therefore they can use the variant of the system that provides full functionality. This variant of the system runs on notebooks or desktop PCs, usually installed on a trailer. These computers are able to be permanently communicated with remote experts through communication infrastructure typically installed in a truck. The work context for remote experts is similar to the people working in the command post, but remote experts are not under the stress of the disaster area. The remote experts are specialists in several areas such as: civil infrastructure, transportation, chemical/biological weapons, explosives, communications and meteorology. The type of remote experts supporting a disaster relief effort depends on the magnitude and type of extreme events to be mitigated.

On the other hand, first responders working in the field need to be communicated with the command post in order to send information, receive orders and update the awareness information related to the disaster situation. The work context for these first responders is uncomfortable, risky, with unstable communications and involves high mobility of the collaborators. The information that first responders need to update and share involves a low data input rate; therefore, their collaborative work is done using a small variant of the system, which runs on a PDA.

Figure 9 depicts a diagram with the concurrent activities performed during disaster relief efforts. Typically the collaboration process requires the command post take the control of the resistance and/or recovery processes. The command post organizes and coordinates teams of first responders working in the field (see Figure 10). It also shares with first responders the basic information about the disaster area, which usually involves maps and data related to stability of civil infrastructure in the disaster area. This information is used by first responders to make collaborative decision-making and to coordinate activities in the field. Some first responders, like structural experts, carry out scout activities, and are able to add and update the basic shared information. This feedback improves the quality of basic shared information that will be used to manage the disaster relief effort. Usually, the command post and first responders need to collaborate in a synchronous fashion

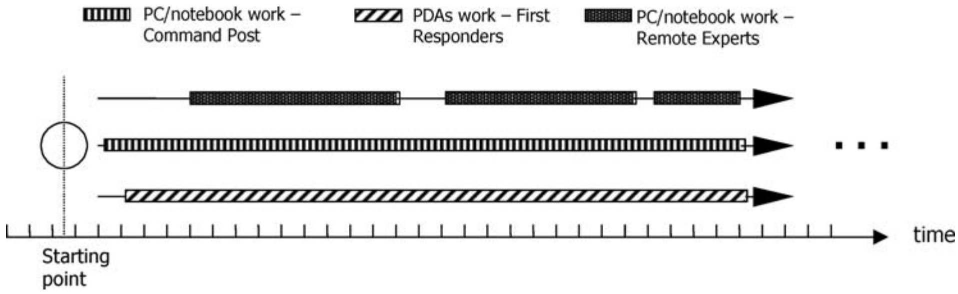


Figure 9. Collaboration activities sequence.

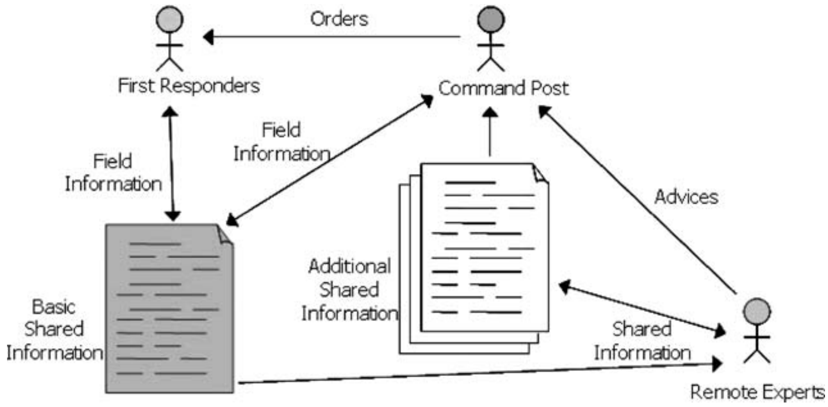


Figure 10. Collaboration process in disaster work contexts.

because the response and recovery processes should be quick and involve coordination activities.

On the other hand, remote experts collaborate synchronously and asynchronously with the command post. The role of the remote experts is to process and analyze the shared information in order to provide advice to disaster relief managers. They can also generate additional information that can be shared with other experts and with the command post. Remote experts can use additional tools such as discussion forums or video conferences to collaborate with other remote experts and generate/validate new ideas.

6.2. CoSDRE (Collaborative Support for Disaster Relief Effort)

The collaborative application that supports the response and recovery processes allows people in different work contexts to share basic information. Consequently, two variants of this application were developed in order to address the requirements imposed by the specific work contexts. The major challenge faced during the development was the design

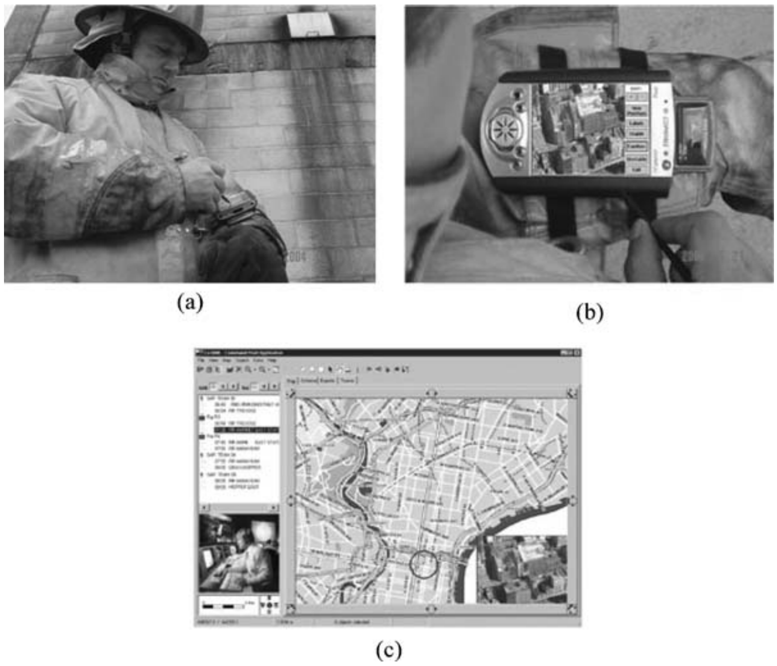


Figure 11. Groupware system to support disaster relief efforts.

and implementation of the CoSDRE variant supporting the collaboration activities of first responders working in the field. That application runs on a PDA located on the arm of first responders (Figure 11(-a)) and the communication support is provided through a MANET. This CoSDRE variant allows sharing graphical objects and the hyperlinks associated to them, which are part of the basic information shared by the participants in the disaster relief effort. The shared information would be updated by the team members depending on the role assigned to each one. For example, information about the structural condition of the infrastructure in the disaster area can only be generated and updated by structural experts or first response team leaders. However, the information entered into the system by structural experts supersedes information generated by others who have a lower role in structural issues. Figure 11(-b) shows the stability of the infrastructure in the disaster area as assessed by the structural experts in a first response team (i.e., red areas for unstable, yellow for caution, and green for stable).

The managers located at the command post and remote experts use the variant of the system with full functionality. That application can link the information updated by first responders with areas in a map (see Figure 11(-c)), allowing a detailed diagnosis of the disaster scenario. In addition, it allows to assign tasks to first response teams and to keep track of the activities carried out by each team. This application has two special collaboration spaces allowing the command post to interact with remote experts and first responders respectively. These collaboration spaces are based on message delivering and a voice conference system for first responders, and videoconference, message delivering and a discussion forum for remote experts.

7. Collaborative Support for Dramatic Production Processes

Making television series is a complex process which can be modeled as the transformation of written text (scripts) into audiovisual products. Several professional groups participate in the recording process. They are responsible for specialized technical components such as set decoration, set assemblies, makeup and costume. Each group has specific functions within the whole process. For instance, the costume group has different responsibilities than the set decoration group.

A TV channel needs a system to support its operation. TV series comprise several chapters. Each chapter lasts about 45 min in this channel production. A chapter is composed of several scenes in which actors play their roles. Scenes have a chronological order, according to the script. However, each scene may be recorded at arbitrary times and places. Of course, when the series are presented to the audience, there must be the right actors' costumes, object positioning on the stage, hairstyling, lighting condition (day or night) and so on. This requires information management at recording time, in order to ensure coherent scene sequences.

Unlike other industries, a TV producing company makes unique products. Thus, a scene typically differs from other ones in terms of involved actors, locations, lighting conditions, etc. Each script generates scene requirements to management. Of course, these requirements condition the planning of scene recordings. For instance, if a certain scarce stage must be used for a short period of time, then all scenes using that stage must be recorded together, independently of the sequence those scenes will have in the final product. Thus, all scenes are characterized by a set of features for later use.

Scene requirements and features allow management to develop a weekly production plan. This plan contains the scenes to be recorded by each recording unit for each day. On the other hand, various documents including all scene details are produced by the responsible groups and must be made available to all involved participant groups. This information must reach the person who needs it on time. In particular, the continuity group is the one handling the largest amount of information.

7.1. Design of the groupware system

This application was developed jointly with a local software company for a television channel. This groupware system is currently used to support the recording of TV series. This system is intended to sustain the collaborative work required by groups of professionals to manage the information generated during the production process. On the other hand, several groups of professionals (not necessarily distinct from the previous ones) use that information to actually make the films. Most work is done in comfortable, stable places and thus, it can be done using desktop PCs or notebooks. However, some tasks are done

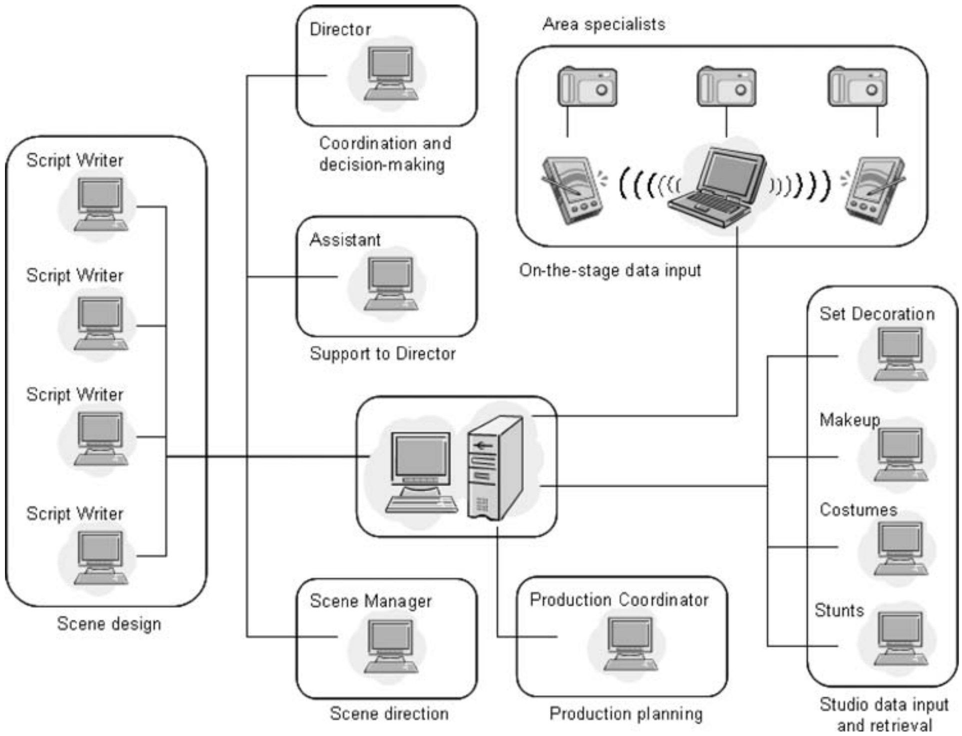


Figure 12. TV Series planning and production support system.

from multiple stages by people with high mobility and low data input rate. Also, some of the scenes are recorded in real out-of-studio scenarios. Thus, considering the specific work contexts involved in the collaboration process, two variants of the system were designed and developed; one for desktop PCs/notebooks and another one for PDAs. Figure 12 depicts a diagram of the whole system. We are focused on the on-stage subsystem because it can be supported in an effective way by using PDAs.

An important part of the computer-supported cooperative work consists of editing documents by multiple users in asynchronous way by role-determined users. Each scene has a life cycle and documents relating to this life cycle are edited before, during and after the scene is recorded. The document editors handle a master document related to the scene, in which the most important data is stored.

7.2. Mobile component of the system

People who are close to the stages must have quick access to the scene sequence for the final story. See Figure 13 for the navigation map. These persons also must be able to input

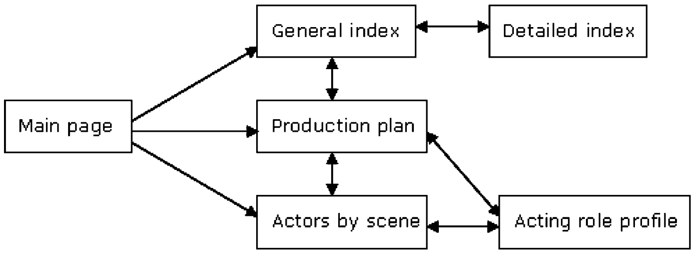
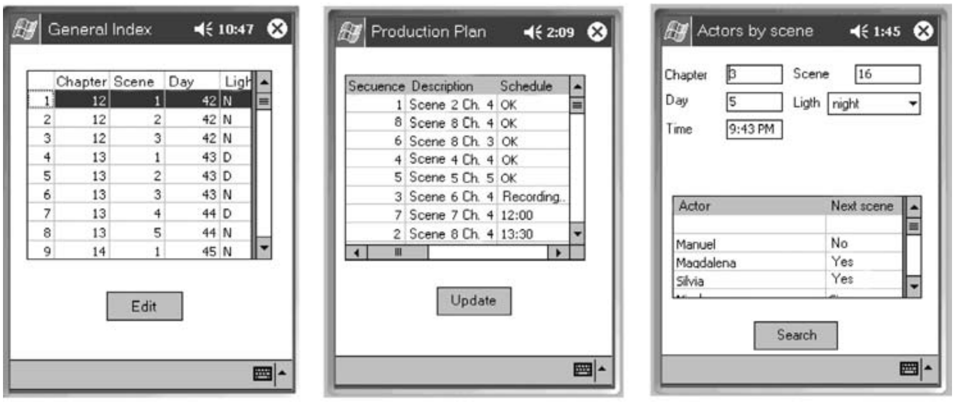


Figure 13. PDA navigation map.



(a) (b) (c)

Figure 14. (a) General index PDA screen; (b) Production plan screen; (c) Acting roles for a scene.

annotations concerning the recorded scenes.

Figure 14a shows a PDA screen of the *general index*, a document relating scenes to chapters and to shooting order. Figure 14b shows a related screen, which presents the daily scene shooting sequence (production plan). Of course, these documents may be updated, so the user may request synchronization if a wireless network is active. Figure 14c shows other details accessible to authorized roles near stages. They concern actors, and so, the director and other relevant personnel can enter or retrieve data concerning the acting roles, scenes and actors preparation.

Each user logs in the system and provides his password through the PDA. Besides identifying the user, the system then associates his/her group role. Now, users are able to use their photographic camera equipped PDAs to input relevant information about the scene being recorded. For instance, the costume responsible can enter information on the clothes being used by the actors, and the hairstyling responsible may input details about wigs being used or hair touches of color. This data may be complemented with digital pictures obtained with the same PDA. A wireless network is established when out-of-studio recordings are made. This network uses a notebook as a server, a wireless switch, and PDA clients. All this captured information is used by the director and his assistants to make relevant decisions.

8. Discussion

Mobile devices are increasingly part of the current technology and thus, we cannot ignore them. That does not mean we should include them in all collaborative systems. On the contrary, in certain cases it may be important to justify why not to include them in the presence of pushing vendors.

We developed a framework based on the three examples we developed before having it. Now, it is interesting to discuss those cases with the framework as a *post-mortem* exercise. Of course, the examples helped to build the framework, thus we should not find surprising results. Instead, we can expect the framework should help to understand the requirements from these example systems, as well as an explanation of the systems deployment results.

The first application (text co-authoring) is a particularly challenging design because traditionally text writing is especially hard to do with handheld devices. We identified a specific work context in which these devices could be useful. In this specific work context, their appropriateness is high while being transported and useful in uncomfortable places. The framework, on the other hand, now warns us that PDAs will be deficient for much data input, and they will be just acceptable for multimedia support and data persistency. The screen size is also just acceptable. These disadvantages explain why our PDA variant of a system has a very limited usability: multimedia material is not easily displayed on the screen, there is only a limited user interface, just little input can be entered to the system, etc. These disadvantages are clear in practice: the application variant for PDA is very rarely used (just to read something instead of writing text). The framework also lets us explain that for our case, the most important reason to decide the development of that application variant was the use in uncomfortable places. Finally, the framework can be used to easily justify the use of desktop PCs or notebooks - and not PDAs - for the other specific work contexts.

The second example was a system to support disaster relief efforts. The work context for managers required management of data from various sources, display of multimedia information, data persistency, large storage capacities and large screen. The framework clearly favors desktop PCs or notebooks. By contrast, the first responders must easily carry the device together with other equipment, they should be able to work while walking and be capable of doing work in uncomfortable places (this is the most important non functional requirement of this application). There is no much input to be entered and a MANET capability is required. The framework shows PDA suitability. Practice shows that PDAs are the best choice to support first responders.

The third example concerned a system to support dramatic productions. This system already existed and the work was to extend it to capture data on the stages. There is little input to be entered to the system and no much contextual information to be displayed. The framework then indicates PDAs could be adequate in this respect: pictures can be captured with a small camera attached to the PDA. The user adds comments to these pictures and afterwards, they are distributed from the server to users requiring them. There are strong requirements on device wearability and work while walking, and then, the framework tells us PDAs are again appropriate for the task. This analysis is confirmed in practice, since the system is successfully used: people like the on-line data capture, as compared with the off-line transcription of hand-written reports and Polaroid pictures of the previous system. It must be further mentioned this system has a stronger coordination component than a collaboration one. Much of the collected information is for the use of the director and his assistants.

9. Conclusion

The frontiers of collaborative work frequently move forward because of technological advances. New collaboration contexts are being supported by mobile computing devices. Now, it is possible to design groupware applications involving several specific work contexts, which impose specific requirements over every software component of a collaborative application. A software piece may be a version running on a specific machine, possibly with an extended/reduced functionality with respect to other versions. Alternatively, a software piece may be a system running on a certain device just to assist a specific functionality (e.g., only to support voting from PDAs).

The key issue is to distinguish all the work contexts involved in a collaboration process and to identify which ones are well-supported with which device(s). Every person participating in the collaboration process should use the most advantageous device with its corresponding software. In that sense, the proposed framework may assist developers to identify the various work contexts to decide which devices could be most useful. Then, developers can start the construction of the relevant groupware (sub)systems.

The framework considers just technical issues to provide the diagnosis. There are several other factors which should be taken into account when choosing specific mobile computing devices to assist collaborative work. These factors include privacy, security, prior experiences, users' attitude towards technology, organizational issues, cross cultural and multicultural issues, collaboration environment, etc. (Mittleman *et al.* 1999; Nunamaker *et al.* 1997). In addition, the framework does not consider other external factors such as the uncertainties produced by the current turbulence on markets, politics and technology (Van de Kar and Van der Duin 2004). An enlarged framework may encompass these factors. Users will ultimately weigh these factors to accept or not a newly developed system. There is work on technology acceptance (Davis 1993) and technology transition (Briggs *et al.* 1999; Agres *et al.* 2004) which is relevant here.

The framework identifies PDAs as advantageous in term of wearability, communication capability and mobility allowed to the user. Mobile phones are well-suited for work contexts where users have high mobility and need to be reachable all the time. Latest versions of PDAs and mobile phones tend to integrate these two types of devices.

Similarly, the current Tablet PCs have the same features than a notebook incorporating some PDA advantages. It is then a hybrid device useful in many cases. We did not have machines of this type when we developed the applications; perhaps today we could develop different applications than the ones we built without them.

Finally, the current notebooks have features similar to desktop PCs, adding mobility to strengths in processing capability and storage capacity. Desktop PCs continue being useful to provide server services to mobile devices.

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