Foundation of a Framework to Support Knowledge Management in the Field of Context-Aware and Pervasive Computing

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Abstract

In this paper we propose a framework to combine Knowledge Management and context-aware and pervasive computing, emphasizing on synchronization and adaptation issues of workflow processes in mobile settings. The key aspect of the proposed framework is to enable adaptive, two-way interaction between context-aware systems and users in mobile settings. In contrast to existing concepts, we aim at capturing active feedback from users, which should contribute to the *Organizational Memory*, after being reviewed, evaluated and classified. Thus, users would not only act as consumers but also as suppliers of relevant information and knowledge to the system and other users. In addition, the concept includes existing approaches to adapt to, for instance, different *Quality of Service* levels in order to provide a maximum level of local autonomy. We suggest using the adaptation concept to also support adjustments to cross-cultural differences in perceiving and communicating information and knowledge. Our work is motivated by the need for a distributed, context-aware and pervasive computing framework to support maintenance and administration tasks related to the International Monitoring System (IMS) of the CTBTO PrepCom, an international organization located in Vienna, Austria.

Keywords: Knowledge management, WfMS, context-awareness, pervasive computing, local autonomy, synchronization, adaptability

1 Introduction

In this paper we combine and expand existing theoretical and practical work in the fields of Knowledge Management (KM) and context-aware and pervasive computing, emphasizing on synchronization and adaptation aspects of workflow processes in mobile settings. We believe that there is a need to combine these efforts into a broader framework, which addresses technical, but also organizational, cultural and social aspects such as organizational and personal knowledge, cross-cultural communication structures, skills, motivation, and experience. In particular, we are interested in the technical, organizational and managerial means to represent and disseminate (local) knowledge and to build up and provide access to the *Organizational Memory* (see Maurer 2001 as well as Kuppinger 2000 and Brown 1998 for similar concepts like *Organizational IQ* and *Organizational Knowledge*) in a mobile environment, using context-specific knowledge and information. This includes the definition of the technical foundation (e.g. definition of domain specific semantics, mobile workflow processes, etc.) but also tackling the challenges that are generally related to developing and introducing a system that requires users to 'hardcode' their knowledge and adapt to new processes and structures (Grudin 1994 and Fahey 1998). We seek to utilize these insights by addressing and including human factors in our concept and pursuing an approach that is not primarily IT-driven. In particular, research on *Communities of Practice* (CoP), an interesting notion of the collective nature of knowledge in organizations, constitutes an important aspect of the foundation of the proposed framework (Brown 1998 and Hildreth 2000). In this paper, however, we will mainly focus on synchronization and adaptability aspects of mobile workflow processes. Similar to Thomas (2002), the framework aims at using the coordination power of Workflow Management Systems (WfMS) in mobile settings.

A key aspect of the proposed framework is to enable adaptive, two-way interaction between context-aware systems and users in mobile settings - focusing on support of remote personnel. In contrast to existing concepts already using active feedback from users to adapt accordingly Piekarski (1999), it is our intention to exploit not only explicit context information such as identity, location, time, and preferences but also tacit information and local knowledge of users. This feedback, in turn, should contribute to the Organizational Memory, after being reviewed, evaluated and classified. Thus, users would not only act as consumers but also as

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The ideas discussed in this paper express the authors' opinion. The CTBTO PrepCom affiliation of Philipp Amann is mentioned to document the excellent support and continuing input from this organization for his research.

suppliers of relevant information and knowledge to the system and other users. In addition, the concept includes existing approaches to adapt to, for instance, different *Quality of Service* (QoS) levels in order to provide a maximum level of local autonomy (Alonso 1995 and Alonso 1997). We propose using the extended adaptation concept to also support adjustments to cross-cultural differences in perceiving and communicating information and knowledge.

The remainder of the paper is structured as follows. Subsection 1.1 provides background information on the case study. In section 2, an overview of related work and relevant literature is given. Section 3 is concerned with the identification of open issues and the detailed description of the problem. Section 4 outlines the proposed solution and, in section 5, a summary of the expected outcome and future work is given.

1.1 Background Information

Apart from academic aspects, our work is motivated by the need for a distributed, context-aware and pervasive computing framework to support maintenance and administration tasks related to the International Monitoring System (IMS) of the CTBTO PrepCom[1], an international organization located in Vienna, Austria. The organization is based on the Comprehensive Nuclear Test Ban Treaty (CTBT), which prohibits all nuclear test explosions in all environments.

The CTBT foresees the implementation of the IMS, which is a world-wide network of 321 monitoring stations and 16 radionuclide laboratories to monitor compliance with the provisions of the Treaty (see figure 1). The IMS is based on seismic, radionuclide, hydroacoustic and infrasound monitoring technologies. These technologies are employed to monitor underground, underwater and atmosphere environments, respectively. Radionuclide stations, for instance, can detect radioactive debris from atmospheric explosions or vented by underground or underwater nuclear explosions.

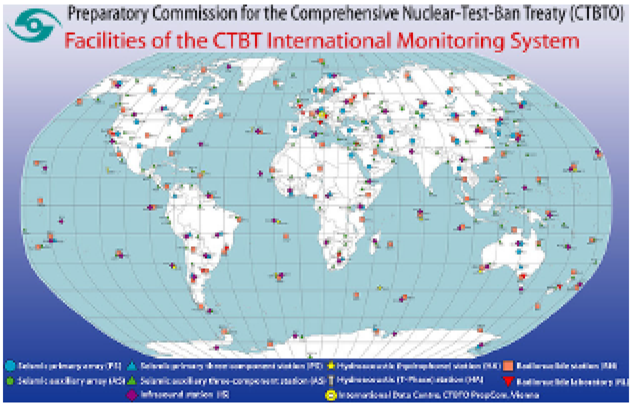

Figure 1: International Monitoring System

The collected data is sent to the Provisional Technical Secretariat (PTS) in Vienna via satellite links where it is being analyzed and combined to reports for member states. Global coverage is being ensured through the Global Communications Infrastructure (GCI), which receives and distributes data through a network of geostationary satellites and hubs (see figure 2).

The basic requirements of IMS stations in terms of installation, data quality and transmission, up-time, security, communication and reporting procedures, and maintenance procedures are defined in CTBTO internal operational manuals (CTBTO PrepCom 2000:1, CTBTO PrepCom 2000:2, CTBTO PrepCom 2000:3 and CTBTO PrepCom 2000:4).

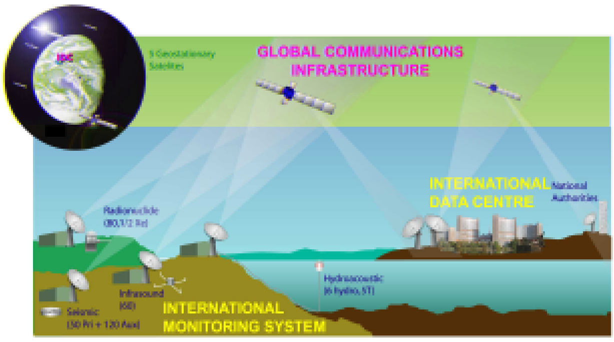

Figure 2: Global Communications Infrastructure

While the manuals define the daily work procedures and maintenance tasks in a general way, there is a lot of tacit knowledge and information that is applied by station operators in their day-to-day work (e.g. calibration of sensors). This knowledge is often created through learning by doing, especially if new equipment is being deployed. To capture and disseminate this local knowledge can be considered very important because of the special-purpose character of some of the equipment for IMS stations.

In addition to this routine work, station operators need to perform scheduled maintenance tasks and send reports on a monthly basis. This monthly report is considered to be a key element in the maintenance of IMS stations as it "[..] provides a consolidated, executive-level overview of all activities and issues that may have impacted station operational capabilities over the previous month. This overview is essential for effective management of the Technical Secretariat cost management system and overall system effectiveness statistics. To ensure these programs are successful, this report must reflect all station issues as accurately as possible.[..]" (CTBTO PrepCom 2000:1, p. 30). As we will mention later, one of the problems with these reports is their official status and the political dimension related to it. Similar problems are described, for instance, in the area of KM for customer support: "support-oriented information can be politically sensitive, because it often involves product and service failing" (Davenport 1998, p. 206). Hence, certain relevant information might not be found in these reports due to political reasons. Furthermore, most of this information is currently not 'actively' used, owing to its limited online availability.

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[1] http://www.ctbto.org, accessed November 2002

2 Relevant Literature and Related Work

This section provides a survey of relevant literature and work in the fields that are of importance to our approach. Due to the fact that Knowledge Management and mobile workflow processes play a crucial role in the proposed framework, the following subsections are geared to these two areas.

2.1 The Field of Workflow Management Systems

In order to support all facets of KM in mobile settings, the combination of GroupWare and Workflow Management Systems (WfMS), despite their different characteristics, is suggested by several authors. The basic idea is to exploit the coordination aspects of WfMS and provide tools to collaborate and communicate (Domingos 1999 and Thomas 2002).

Although the Workflow Management Coalition's Workflow Reference Model[2] foresees some basic concepts to support mobile and distributed workflow management (WfM) (e.g. electronic mail model, remote procedure call and message passing model), there is currently no adequate support for WfM in mobile settings, which has led to several different approaches to tackle the problems linked to mobile settings.

Research in this area is concerned with distributed workflow frameworks, disconnected clients, survivability and synchronization of (mobile) workflow processes, to mention some (Alonso 1995, Cardoso 2001, Domingos 1999, Heinl 1999, Jing 1999, Purvis 2000 and Reichert 1999). The goal is to develop concepts that can deal with the special characteristics of mobile settings without jeopardizing the overall workflow process, keeping persistency but at the same time keeping a maximum level of local autonomy. Users of such solutions are, for instance, healthcare, utilities, surveying, transportation, telecommunications, and emergency response organizations.

One of the identified restrictions of current WfMS pertains to the lack or insufficient support of incomplete task definitions. To lift this restriction is particularly important, as task definitions in mobile settings are likely to be completed/complemented by information or local knowledge only obtainable at physical locations.

Existing WfMS can be classified according to their WF definition scheme. For instance, one can distinguish between process and activity structures ranging from very rigid and inflexible (pre-defined process and activities which are typically found in administration) through more flexible structures (pre-defined activities and ad-hoc processes) to very flexible, human-centered structures, which support ad-hoc processes and ad-hoc activities. Because of the time and expertise needed to define workflows, ad-hoc modeling is seen by some authors as a contradiction in itself (Alonso 1997 and Heinl 1999]).

2.2 Relevant Frameworks, Approaches and Technical Infrastructures

In the area of WfMS, several frameworks and approaches have been described to support distributed and/or mobile environments. In Heinl (1999), for instance, a comprehensive approach to flexibility in WfMS is described, focusing on adaptive workflows i.e. workflows that can adapt to exceptions and changes of business processes. One of the central concepts of the approach is *descriptive modeling*, which is based on late modeling. Using descriptive modeling means to omit certain definitions of the workflow type at modeling time, which provides the end user with more flexibility. Of course this also requires end users to have the necessary knowledge, skills and expertise to chose the proper action. The implementation of descriptive modeling, which has been incorporated in the *Mobile* WfMS by the authors, is based on a perspective oriented workflow model where each perspective represents an independent modeling aspect.

Reichert (1999) focuses on the high-flexibility, maintainability, and scalability of enterprise-wide and cross-enterprise workflow management systems. The authors discuss adaptive WfMS, which support run-time changes of WF instances i.e. adaptations at the execution level. In contrast to Heinl (1999), this approach focuses on the support of ad-hoc deviations from pre-defined workflow schemas at the instance level, which may be necessary to handle exceptions or support late modeling. Some of these features have been developed as part of the ADEPT project but due to the non-trivial character of dynamic WF changes, a number of open issues like semantic rollback, security, and handling of privileges and roles still remain.

In Domingos (1999), a workflow architecture to manage collaborative work is discussed. The definition and implementation is based on a case study, which took place in the electrical industry. The authors point out that "in mobile collaborative scenarios, pre-defined processes are too restrictive and there is high probability of conflicts/divergences as well as communication failures, involuntary disconnection and more problems to deal with high availability and reliability in resource sharing" (Domingos 1999, p. 4). The proposed workflow architecture is based on loosely defined workflows supporting a hierarchy of decentralized organizational workflows with different levels of specialization and work-control granularity. The basic idea is to not over-specify tasks. Some of the shortcomings are:

- Planner-Team approach requires considerable coordination, which is put on the planner and realized through election mechanisms;
- The actual integration of local updates to the global state of the WfMS is not described in detail;
- Lack of KM concepts.

Jing (1999) distinguishes between *location-independent* and *location-dependent* mobile workflow applications. Each type requires different mobile support (e.g. on-call field service is spatial in nature and therefore location-dependent). Location-independent activities are

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[2] http://www.wfmc.org, accessed November 2002

characterized by a high level of structure and pre-design because input and output is better predictable. Based on two different examples, the authors look into strategies to support *workflow-specific* and *application-specific* adaptations. The first type of adaptation performs optimization by re-scheduling and sequencing multiple work activities dynamically whereas the latter type uses user knowledge and application semantics like the consideration of different QoS levels of the underlying communication infrastructure for optimization purposes.

In Davies (1995), application-specific adaptation is also identified as an effective way to support mobile applications. At a more technical level, the authors describe the implementation and use of a platform designed to support collaborative multimedia applications in a mobile environment as part of the Mobile Open Systems Technologies (MOST) project. The purpose of the project is to study the requirements of field engineers within the U.K. power distribution industry. Through explicit binding of communication streams, the platform supports testing of and adapting to different levels of QoS without having the client to take care of the actual technical implementation. The technical realization of the corresponding protocol – QEX – is described in Davies (1996). In addition, the system provides visual, context-specific feedback to the user on the state of communications between all conference participants and collaborative tools. Thus, the user can select the appropriate communication channel, based on a given QoS level.

An interesting approach to survivability of WfMS, using KM concepts, is described in Cardoso (2001). The idea is to adapt workflow processes in response to exceptions, which are handled by exception handlers using existing knowledge. The authors define *survivability* as "the capability of a workflow management systems to maintain a pre-established acceptable running mode and behavior after the occurrence of unexpected errors, accidents, failures or attacks, in a timely manner and to allow the adaptation and evolution of the supported processes in response to its surrounding environment" (Cardoso 2001, p.2). It is interesting to note that this definition is geared to exceptional, catastrophic events and does not include the 'natural' disconnection that occurs in mobile settings. If no exception handler can be found to handle an exception human input is required, which will be stored in the Case Based Reasoning (CBR) system for future reuse. Thus, the exception resolution process is actually the population process of the CBR system. While using an intelligent CBR mechanism to reuse existing knowledge in handling exception is a promising approach, the proposed solution does not elaborate on the actual semantic impact of dynamic changes to running WF instances. The concept relies heavily on the knowledge and input by humans in the 'learning stage' but is able to reuse this information in future scenarios. It does not, however, consider mobile aspects.

In Fagrell (2000), an architecture to support mobile collaboration is outlined. It facilitates filtering of tasks using agents, including several, heterogeneous backend information systems, flexible and adaptable views on information, and task-dependent access to experts. It is designed to support autonomous and creative activities in mobile settings, providing collaboration through *interest profiles*, which are automatically created for a task through extracting keywords from that task. If interest profiles (i.e. tasks) overlap, the user will see the name of the corresponding user and her availability (considered as an 'expert' for the task at hand). The prototype described supports news journalists - as a consequence, experts are selected based on authorship but not information provided by the user. Furthermore, the system requires a strong attitude of sharing and collaboration and does not support structured tasks. There is also no explicit feedback component to capture relevant information and knowledge in the field.

The model proposed in Thomas (2002) aims at integrating existing backbone information systems like WfMS in mobile computing, in particular in outdoor wearable augmented reality computing to support collaboration across a number of application domains. To this end, an O*utdoor Wearable Augmented Reality Collaboration System* (OWARCS) is introduced. A medical emergency scenario using an advanced control/analysis room concept demonstrates the practical relevance of the OWARCS. Similar to notes and annotations as used, for instance, in Reddy (2001), the OWARCS supports augmented reality information stickers (e.g. audio messages) to be placed on an object via an eye cursor. The authors identify synchronization and coordination of processes running in parallel as well as handling of communication interruptions as major difficulties. As a solution, the authors propose to link traditional WfMS to a message based enterprise bus like ELVIN (Fitzpatrick 2000 and Sutton 2001, see also section 3). The paper further outlines the different components of an advanced control room environment, emphasizing the importance of adaptability, synchronization, flexibility (e.g. rapid configuration to support different display and computing devices), and robustness. One important difference to the approach discussed here is that the OWARCS focuses on reusing existing knowledge whereas we also intend to explicitly support the capture and dissemination of new knowledge.

Bialek (2001) details a project that supports a specific WF process (ordering and measuring of blood samples) in a hospital, using hand-held devices. The main goal is to define a mobile, reliable solution, which provides a maximum level of local autonomy i.e. the mobile client should work continuously even in case of network disruptions. The communication concept between client and server is using a Message Oriented Middleware (MOM), which stores and forwards messages in a reliable and persistent fashion. The concept also investigates means to recover from different types of software faults. To this end, it utilizes watchdog processes to monitor the application modules. The proposed concept focuses on just a particular WF process and considers adaptation at the communication layer only. However, the technical concept is a very useful starting point for the technical part of our approach.

2.3 Knowledge Management and Mobility Aspects

Research on KM in mobile settings employs concepts like *local knowledge* (i.e. knowledge specific to individual users, places, procedures and situations; created through local experience and used locally) and CoPs, which hold collectively produced knowledge, to describe the special characteristics of mobile, distributed KM processes.

The important role of local knowledge in mobile settings is discussed, for instance, in Fagrell (1999). The authors argue that particularly *remote mobility*, which is defined as remote users interacting with each other using technology, is closely related to local knowledge.

Along with KM studies in mobile settings, there is a basic recognition of the importance of individual and group differences, including of course cultural differences. Hayward (1997), for instance, presents an interesting study on culture - defined as the collective programming of the mind which distinguishes one group from another - and aviation safety. The need of KM to adapt to local settings is also identified in Teece (1998). In this context, the concept of *Boundary Objects*, which are defined as artefacts (e.g. shared documents) used by communities to transfer knowledge over boundaries between them, has been introduced. Boundary objects are generic enough to be transferable but robust to retain their structure. However, their transfer often needs to be supported by tacit knowledge and expertise as they can be interpreted differently, particularly in international environments (Hildreth 2000). In Reddy (2001), the role of medical records as boundary objects in a Common Information Space (CIS) is discussed. At a more theoretical level, Dourish (2001:1) discusses boundary objects in the form of process descriptions in WfMS.

Closely related to the work linked to mobile settings, is the work on software agents, which are basically autonomous entities that can communicate with other people and agents to fulfil complex tasks, sometimes on behalf of a human being. As such they can be used, for instance, in mobile, heterogeneous environments to work on tasks while the user is disconnected from any server/service as well as virtual team members and tutors (Bradshaw 1997 and Cabri 1998). The use of software agent technology can add significantly to the usefulness and practical relevance of our approach. Especially information retrieval in the field, where continuos and permanent network connection is generally not available, can be supported by software agents. The actual incorporation of software agent technologies is envisaged at a later stage, after the implementation and evaluation of the current approach.

3 Problem Description

Current shortcomings and limitations in the area of context-aware and pervasive computing can be attributed to technical aspects (Sohlenkamp 2000) as well as inadequate or lacking organizational, managerial and psychological concepts and measures, as discussed in (Dourish 2001:2, Grudin 1994 and Shipman 1994). The findings include discrepancies in the way benefits are perceived by management and individuals, problems with inadequate and cumbersome information and knowledge structures, difficulties in eliciting and/or revealing workflow processes and the importance of managerial and key user support. Additional problems concern the need to learn and adapt to new formalisms and the disruption of social processes. These shortcomings and problems prevent or limit the success of such systems by failing to support and motivate users to actively participate and to share relevant information and knowledge. Last but not least, technical restrictions (e.g. limited CPU power and physical memory, short battery life, small screen size, etc.) have been the cause of difficulties and limitations in practical settings (Brodie 2001 and Sohlenkamp 2000).

Another problem with most interactive computational technologies is their complexity, which makes them extremely obtrusive elements of our working environment – sometimes even requiring the adaptation and redesign of practices, organizational processes and physical settings to accommodate usage (Dourish 2001:2). This has led to a number of unsuccessful and difficult projects like the UK air traffic control center at Swanwick, which took six years longer to become operational than originally planned, was greatly over budget and, above all, still has some severe technical and user interface problems (e.g. font size used to label aircrafts on the monitors is too small)[3].

On the other hand, successful interactive technologies like ELVIN (Fitzpatrick 2000) have created considerable attention, particularly because of the unobtrusive characteristics of applications using the ELVIN infrastructure like the TickerTape interface. The importance of these characteristics is also recognized by ELVIN’s authors who stress that without the Tickertape interface “[..] it is doubtful whether its [ELVIN] potential for support of awareness and interaction would have been realised” (Fitzpatrick 2000, p. 27).

The reason for selecting the IMS as a proof of concept for our framework is connected to current infrastructural and technical difficulties pertaining to different equipment, several different information sources as well as the localization of knowledge (‘ know how’ but also 'know who') and the graphical distribution of stations. Several different software packages are used, for instance, to maintain and administer stations and gather feedback. Furthermore, the geographical distribution of the IMS network and the resulting cultural diversity brings about a number of issues, which manifest, for instance, in different ways of communicating and perceiving knowledge and information. Last but not least, there is an expressed need of station operators for adequate support in disseminating relevant information and knowledge among them.

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[3] See, for instance: http://news.bbc.co.uk/hi/english/uk/newsid_1936000/1936464.stm, accessed May 2002

The subsequent paragraphs summarize the current issues and difficulties pertaining to the administration and maintenance of IMS stations:

General aspects:

- The geographical distribution of stations creates not only technical challenges but also legal and political issues, which need to be resolved. Some of the equipment used to monitor environments has been specifically developed for the IMS (e.g. partially blinded sensors). As a consequence, it is not possible to make use of previous experience with such equipment. Thus, dissemination of relevant information and new knowledge among station operators is an important requirement;
- The IMS has special requirements in terms of up-time, data accuracy and security. In general, the PTS has special interest in analyzing unforeseen problems and unscheduled repairs;
- Maintenance procedures, work routines, etc. are currently described at a high-level only. There is a need to specify procedures i.e. workflow processes at a more detailed level;
- Software for station equipment and the equipment itself is provided by different external companies, using different formats and guidelines.

Technical aspects:

- Currently there are several different information systems used to provide feedback on problems. The information is mainly used for documentation purposes and not or only limited available on-line;
- Not all stations have the same level of connectivity. Therefore, offline media (e.g. manuals, CDs) are important as well as achieving the highest level of local autonomy possible, especially for stations with bad connectivity;
- Any interactive, context-aware system needs to be integrated into the existing communication infrastructure. It is necessary to reuse existing data formats and aim at a rather lose integration in order not to cause any disruption to the existing software systems;
- The existing information systems do not support station managers in an adequate and optimal way. One of the systems, the Experts Communication System (ECS), which we have designed and implemented at the PTS in 2001/2002, has failed to support station operators due to both political reasons and technical restrictions (secure access, not all relevant information available, etc.). One of the problems, as described also in (Grudin 1994 and Shipman 1994), pertains to the dilemma of official vs. unofficial rules. Because of the fact that ECS is primarily used for exchanging diplomatic and political views, station operators would not reveal relevant information as such information might cause potential political problems. Recent field studies with a dedicated 'Intranet' system for station operators, provided and hosted by a commercial company, showed a much higher level of acceptance.

Human aspects:

- Due to the fact that the IMS is in the installation process some stations are more advanced in terms of equipment installed and certified and sending data to the PTS. As a consequence, the levels of experience and local knowledge differ among station operators. Due to technological progress and the resulting deployment of new equipment, this will remain relevant even after the completion of the initial installation;
- The above mentioned cultural diversity influences the way context-aware guidance and support is perceived and knowledge and information is communicated. Another important aspect in this context is the consideration of language barriers;

4 Foundation of Framework

As already mentioned, we propose a new framework based on context-aware and pervasive computing concepts to support KM in a distributed environment. We intend to provide decision support in the field and assist with the dissemination of relevant information and knowledge among geographically distributed communities with different cultural backgrounds.

Our emphasis is on communication and interaction aspects but we need to also investigate rule and process-based policies that are flexible enough to ensure a maximum level of local autonomy. For this purpose, we introduce a flexible mapping of global processes to local versions, which depend, in turn, on locally available skills and knowledge.

We further propose an adaptive approach at the technical level (e.g. different QoS levels of communication channels as described in Jing 1999) as well as at the semantic level (e.g. use of profiles in combination with descriptive workflow definitions) (Heinl 1999). Especially descriptive modeling is a good candidate to provide the required structure of tasks and processes but also the necessary flexibility to adapt to different levels of local expertise, thereby determining the level of local autonomy.

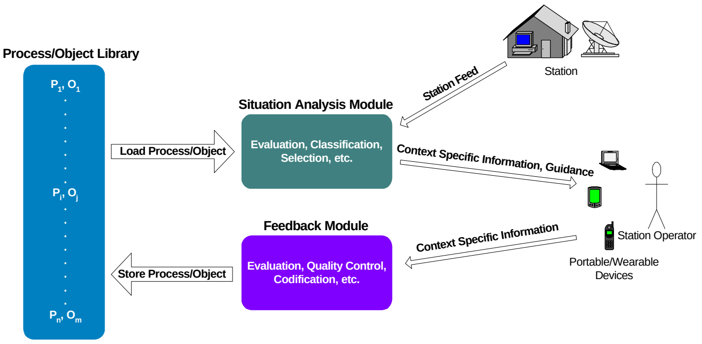

Figure 3: Context Aware and Pervasive Computing Framework - Technical View

The proposed framework represents an integrated approach, which includes organizational, managerial and technological aspects. The key idea is not the invention of a new technology but the intelligent integration and exploitation of existing concepts and solutions. In particular, we propose to integrate open standards to ensure platform independence and facilitate the development and integration of new requirements, concepts and third-party tools.

As part of our effort, we need to address the following issues:

- Context-specific provision and capture of information and knowledge, using pervasive computing;
- Adaptation of mobile workflow processes to local settings;
- Identification of re-synchronization requirements;
- Identification and implementation of adequate caching and recovery strategies;
- Robustness of mobile workflow processes;
- Resolution of update conflicts;
- Appropriate user interface design.

As mentioned in section 1, we use IMS as a proof of concept. The main idea is to support station operators in the field by providing context specific information and knowledge, using wearable equipment (see figure 3). As pointed out before, the consideration of human aspects such as cultural differences, different levels of motivation, and language barriers will be crucial elements during the design and implementation phases.

The following subsections describe and define various aspects and components of the proposed framework in more detail. We particularly focus on synchronization and adaptability aspects of workflow processes.

4.1 Application Scenario

Within the IMS context, four main user groups can be identified:

- Stations operators;
- National Data Centre (NDC) personnel;
- PTS staff;
- Contractors.

The tasks of the first group, station operators, were already described in section 1. NDCs are responsible for collecting raw data, automatic and interactive processing of data as well as providing interactive access to the member state they belong to. They also provide technical support to local station operators. PTS staff in the IMS division has basically the same tasks as NDC personnel but must review data from all stations and provide the results in a timely manner to all member states, ensuring a high level of quality. Furthermore, PTS staff is responsible for the overall maintenance and administration of the IMS, including the archiving of data. The activities of PTS staff also comprise the drafting of operational procedures, the testing of equipment, the supervision and support of the installation of stations, the certification of installed stations, and the monitoring of stations, to list the most important. NDC personnel as well as PTS staff need to collaborate and coordinate with local and global contractors like the operator of the GCI and provider of third-party products. As a result of this division of responsibilities and the geographical distribution, relevant knowledge and information is not equally distributed and not accessible to all groups.

Because of this and the fact that all four groups are engaged in various communication processes during normal operations and emergency situations, they need to be included in the framework, even though the primary focus is on station operators.

The following three operation types are of relevance to our framework, as they require support in the field as well as collaboration and communication with others:

- Normal operation (e.g. routine operations as defined in the operational manuals, scheduled maintenance tasks, etc.);
- Handling of exceptional situations (e.g. disruption of connectivity, disruption of SW service, broken sensor, broken antenna, database crash, etc.);
- Handling of new situations (e.g. new equipment, experience with different new settings, etc.).

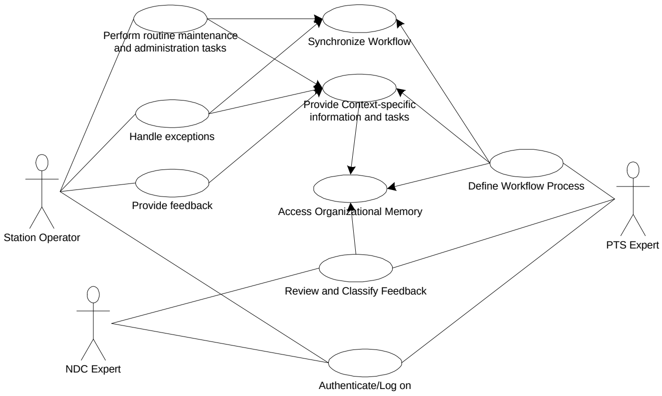

Figure 4: Application-specific Use Cases

In order to meet the special requirements of the IMS, the framework must utilize a modular synchronization concept that supports different synchronization and adaptation strategies based on static information but also context-specific information and local knowledge available at the station. The rationale behind it being that NDC and/or PTS experts should be able to either specify the synchronization requirements of a given WF process at modeling time i.e. leave the server in full control or leave it up to the client to select the appropriate synchronization concept, using information about the context of the user in connection with the task at hand.

The relevant actors and use cases are depicted in figure 4.

In order to map these use cases to the framework, it is necessary to define possible strategies to achieve the envisaged modularity and flexibility.

Roughly speaking, two basic strategies can be identified:

- If the level of local knowledge available at the station is low, the server (i.e. NDC and/or PTS expert) will prefer to stay in full control and, thus, impose rather strict synchronization requirements on the client (i.e. station operator). As a consequence, the level of local autonomy will be low and no or just limited feedback will be required from the client;
- If there is a high level of local knowledge the server will define rather loose synchronization requirements i.e. the user will have more flexibility in working on tasks, thereby achieving a higher level of local autonomy. However, the server might have more interest in feedback by the client to store and disseminate this feedback, as appropriate, but also as a means of monitoring the overall WF process.

In order to achieve full flexibility and the highest level of local autonomy possible we choose adaptable approaches in the following areas:

- Workflow definition;
- Adaptation to local knowledge and expertise (e.g. profile-based);
- Adaptation to local technical factors and requirements (e.g. QoS).

4.2 Definition of Context in the Application Scenario

In Korkea-aho (2000), *context* is defined as “any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and the application themselves” (Korkea-aho 2000, p. 2). Context information can be identity, spatial information, environmental information (e.g. temperature, light, noise level, etc.), social situation, availability of resources, activity, etc.

In figure 5, we provide a high-level view on what we define as *local context* in a remote mobile setting. The right-hand box represents the main primary factor of the local context of the mobile user (the station operator in our example). In our definition, *primary factors* comprise all knowledge and information sources as well as all communication channels that directly determine or affect the local context of the user. In addition to the technology-based primary factors, the context of the user is influenced by ‘off-line’ knowledge, information and data sources such as manuals, CDs, videotapes, etc.

Last but not least, face-to-face communication with other users in the same or similar settings represents a key primary factor of the user's context. Although we recognize the important role of face-to-face communication it is not the main focus of our work mainly because of the remote mobility aspect and our global view on disseminating relevant information and knowledge among users in such an environment. Nevertheless we do agree on the importance of utilizing local knowledge as a result of social, dynamic and cooperative processes along with the authors of (Fagrell 1999). Thus, face-to-face communication should be considered as a valuable source of information and knowledge transfer. With reference to our case study, this means that already existing measures like on-site training, regular meetings of station operators and site surveys should keep their important role.

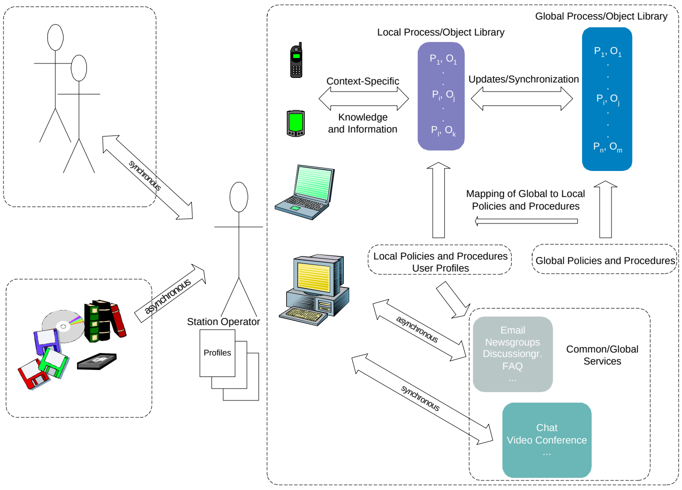

Figure 5: Context of Station Operators - Primary Factors

In addition to the above-mentioned primary factors, there are a number of *secondary factors* (in the context of our framework) that have a significant impact on the context of the mobile user. These factors include culture, social settings, and education, among others. As mentioned earlier, we propose to utilize flexible mapping processes and adaptable workflow processes to take into account their different values and qualities.

Using this definition of context as a basis, we are interested in disseminating relevant information and knowledge in a context-aware manner. Thus, we need to gather and evaluate context-specific information on stations to be able to provide problem-specific solutions, for instance. This includes *state of health information* as it is already produced and sent to the PTS. However, this information is currently not used to actively induce any workflow processes or other activities on-site. In addition, we need to gather *spatial*, *time* and *resource* information to be able to support station operators in the field, using, for instance, wearable equipment.

4.3 Definition of Local Autonomy

A central aspect of our framework is the notion of *local autonomy* which, in our practical context, refers to the ability of station operators to conduct scheduled and routine operations and to react on unscheduled technical problems in an independent way i.e. without or just limited online access. Thus, local autonomy comprises all activities and workflow processes that can be carried out with limited system support. Consequently, the notion of local autonomy is closely related to adaptability and synchronization of workflow processes.

We define local autonomy also in relation to global policies and procedures that are mapped to local versions, depending on locally available knowledge as well as user profiles (see figure 5). As a result, local autonomy can have different levels of occurrence, thereby considering local and individual differences. Ideally, the level of autonomy should increase over time for standard operations and exceptions as station operators gather experience and relevant knowledge and information. Clearly this means that the experience and knowledge of the station operator needs to be reflected in his or her profiles, which is beyond the scope of this paper.

Apart from the proposed mapping of global policies and procedures to local versions, local autonomy also requires a local copy of the maintenance process and object library to provide context-aware information and knowledge. For this purpose, the proposed framework must foresee a distribution concept of the global knowledge and information repository. Depending on the level of connectivity, different update schemas have to be defined, which, in turn, influence the level of local autonomy.

4.4 Synchronization and Adaptability Aspects

Synchronization and adaptation of workflow processes has to be dealt with at several different levels: the infrastructure level (OS, Hardware, communications, etc.); the workflow level (WfMS components); the schema level (workflow schema definition); and the instance level (application execution of workflow tasks) (Cardoso 2001).

The following bullets list some of the open issues and problems that need to be addressed in this context:

- Identification and classification of mobile workflow processes;
- Classification of global and local workflow processes - the system has to know in advance which subtasks can in principle be processed in an autonomous way;
- Adaptation of workflow processes in relation to global and local policies and rules;
- Handling of disruption and definition of resynchronization points and rollback procedures;
- Capture of local knowledge and experience as part of the workflow process.

The first two bullets are linked to the definition of the different types of disruptions and their occurrence (e.g. before the start of a WF, during the execution and after completion), which, in turn, has to be combined with the different classes of tasks and processes (e.g. some mobile processes are more ‘sensitive’ to disruptions than others). This means that the framework must support the definition of different task and process classes at the modeling stage. We propose the following two basic classes of WF processes and tasks, which can be extended as needed:

- Normal – synchronization requirements depend on global and local settings and rules;
- Critical – cannot be executed and/or modified locally but need to be synchronized with the WfMS.

We propose using a flexible workflow and task definition approach to define the basic levels of local autonomy but to allow for different local settings. This means that it is up to the designer of the workflow to indicate whether a task can be modified and executed locally, using, for instance, late modeling, or whether it requires real-time synchronization. The idea behind it being that it requires in-depth understanding and knowledge to define and exploit the maximum level of local autonomy possible, considering also the different levels of local knowledge and expertise.

In addition to specifying synchronization requirements, the framework must also support the context-specific gathering of relevant information and knowledge (similar to the before mentioned visual markers in Thomas 2002). Thus, the feedback component must be combined with the workflow component to link this information to the corresponding process. As discussed in the literature, it is important that the actual method used to capture feedback is unobtrusive and does not interrupt the task at hand. This means, for instance, that the mobile user is not forced to provide feedback in a structured fashion. A proven way of minimizing obstruction and disruption is the use of voice recording (Thomas 2002) as well as visual feedback (e.g. pictures and videos). Therefore, several technical means like voice recording and electronic notes have to be provided to capture feedback, which is reviewed, evaluated and classified at a later stage. We discuss the feedback component in more detail in the next section.

4.5 Visualization and Interface Issues

Visualization plays an important role in KM due to the amount and complexity of information that needs to be displayed as well as the adaptation to special requirements and restrictions (e.g. limited screen size, unobtrusive provision of information for pilots). Optimal design of user interfaces is becoming ever more important to transfer information and knowledge and, at the same time, create use acceptance. This is particularly true for Augmented Reality (AR) systems, where visualization techniques play a paramount role (Azuma 2001, Brown 1998, Fagrell 1999, Fagrell 2000, Hildreth 2000, Pappas 2002, Piekarski 1999, Quirchmayr to appear, Sutton 2001, Thomas 2000, Thomas 2002, and Tagg 2002).

For our purposes, we also need to look into visualization and interface aspects regarding the capturing process of knowledge and information. In particular, we have to investigate the following two areas:

- Visualization of context-specific information and knowledge in the field (e.g. availability of resources, quality of communication channel);
- Gathering of context-specific information and knowledge in the field.

We propose to base the visualization concept on device and platform independent standards and to separate it from any program logic. For this purpose, we follow an n-tier client/proxy-agent/server approach (as described in Bialek 2001), using open standards to describe our data. The actual physical devices used to present information to the user should not affect the storage and business logic layers on the server but only define the formatting process and the set of available functions (depending on physical attributes like screen size and computing power). From a design point of view the actual interface, in combination with the physical devise used, has to be unobtrusive and intuitive in use to minimize disruption of any work and social processes (Azuma 2001, Grudin 1994, Quirchmayr to appear, Shipman 1994, and Thomas 2002).

The more interesting part of the visualization concept pertains to the interface design to capture context-specific information and knowledge. Apart from any automated mechanisms based on the actions of the user (automated classification, automated inference, etc.), we need to provide an active way of capturing information and knowledge in the field. Again the technology and design used has to be unobtrusive and not too structured and formalized. As pointed out in Shipman (1994), most existing examples suffer from enforced formalization i.e. the usage of premature, not suitable structures; cognitive overhead; and disregard of individual differences and situational structures. The authors identify gradual formalization and restructuring as one important remedy to overcome these problems.

4.6 Integration in Existing Information Systems and Security Infrastructure

Explicit knowledge and information is stored (or sometimes ‘hidden’) in various different information systems, using different formats and structures. Access to these information systems normally requires special clients, which can make searching over several information sources and combining and accessing more than one information source a difficult and time-consuming task. While it can be argued that the number of clients to access the various information systems should be minimized (using, for instance, a portal as a single point of information access), it is in general not feasible and/or reasonable to unify information systems because of the different requirements, scope and special solutions provided by them.

A major aspect of the proposed framework is therefore its openness and flexibility in interfacing to other information systems. To this end, the use ELVIN (Fitzpatrick 2000) and its extension to facilitate support of mobility by introducing a proxy concept (Sutton 2001) is foreseen.

From a practical point of view, the framework must provide connections to the following existing information systems:

- Document Management System (accessible via CORBA and Java Beans);
- Database Of the Technical Secretariat (DOTS) to retrieve information on station equipment (accessible through Java Server Pages and Java Beans);
- State of Health Monitoring System.

As security plays a crucial role in the IMS, a system-wide Public Key Infrastructure (PKI) has been put in place to digitally sign and encrypt all data coming from stations. This ensures that the data has not been tampered with. Assuming that maintenance specific information and knowledge are confidential as well, the framework needs to utilize the PKI as well.

Finally, interoperability with the existing structure and syntax of control commands for IMS stations has to be guaranteed (CTBTO PrepCom 2001).

4.7 Organizational, Managerial and Administrative Aspects

As stressed elsewhere, we aim to include organizational and managerial aspects to support the acceptance of the framework, ensure its practical relevance and induce the necessary individual efforts to actively use it.

The following subsections summarize key aspects that we intend to address in our framework.

4.7.1 Integration of Key Users and Decision-Makers

Many authors have identified the importance of including users in the design process, and the development and test phase. In Grudin (1994), for instance, this is referred to as managing acceptance, which basically means to integrate key users but also to manage the needs and demands of managers and non-managers. While a context-aware framework that utilizes and adds to the organizational memory may immediately appeal to a manager, he or she may underestimate the downsides in terms of unwelcome extra work for the users, disruption of existing and functioning processes, the need to reveal tacit knowledge, and so on.

Thus, it is required to include decision-makers as well as key users in the design and development phase. In particular, the support of key users is crucial to the success of the proposed framework, as they are the main customers of the system and ‘suppliers’ of relevant information and knowledge. The identification of key workflow processes and the definition of structures and formalisms to support users but also to capture their input are critical design aspects, which will require the support and input of key users. They should be chosen according to their experience and knowledge but also their ability to create opinion, as they will substantially contribute to the overall perception of the system.

At the management level, it is crucial to get the required support (or *critical mass* as it is put in Korkea-aho 2000) to get access to the required resources and to ensure the necessary funding.

4.7.2 Review Processes

Systems that aim to capture (individual) knowledge and specific information generally require review procedures to ensure the accuracy and relevance of captured knowledge and information. Furthermore, it is necessary to classify and link new knowledge and information to existing repositories, which can be a difficult and time-consuming task. There are a number of different computer-supported classification techniques (e.g. graph theoretic techniques, artificial neural network techniques, evolutionary approaches, etc.) that can support the review process but, for the time being, it can be assumed that the final quality check still lies with human beings.

The importance of reviewing processes is generally accepted in the literature. Lundberg (2000), for instance, suggests investigating into the methodologies for building networks of co-operating partners and the determination of necessary support systems to handle the contributing and reviewing process effectively and efficiently. Similar arguments can be found in (Grudin 1994, Maurer 2001 and Shipman 1994).

However, as mentioned before, it is important to design review and evaluation processes in a way that they do not create excessive burden or cognitive overhead for those carrying out the processes. It is also suggested to assign roles to people for periodical reviews (Fagrell 1999).

For the design of the review processes we intend to also use adaptive review and structuring processes to minimize obstruction and disruption of workflow processes.

5 Conclusion and Future Work

We have discussed the foundation of a framework for context-aware and pervasive computing that supports knowledge management in mobile environments. The design of the framework is based on existing concepts and focuses on synchronization and adaptability aspects of mobile workflow processes as well as gathering feedback in mobile settings.

We have further argued that it is crucial to abandon the prevailing IT-driven view in this area and also focus on the psychological and cultural aspects of interaction and communication. To this end, we include management and key personnel in the design and deployment process and focus on representation and localization mechanisms that support different levels of local knowledge and cultural background in a flexible way.

From a practical point of view, the prototype implementation is expected to yield a higher level of quality of maintenance and administration as well as a significantly higher level of sharing and dissemination of relevant information and knowledge among station managers.

The following bullets summarize the expected results and benefits at the different levels:

<u>Organizational and Managerial level:</u>

- Support for synchronization and adaptability of workflow processes;
- Personalization of information and localization;
- Minimizing the drain of knowledge by capturing and disseminating relevant information and knowledge;
- Definition of adaptive processes for mobile support, reviewing and feedback;
- Means to complement face-to-face communication;
- Consideration of multi-cultural aspects.

<u>Maintenance level:</u>

- Access to context-relevant information, using any device (e.g. laptops, PDAs, etc.);
- Single-point of access i.e. one interface to access information and data from various sources such as documents, databases, image repositories, etc.;
- Combination of online and offline media;
- Possibility to store/codify maintenance specific information and knowledge.

<u>Technical level:</u>

- Definition of domain specific ontology to support codification, exchange and retrieval of maintenance-specific information and knowledge;
- Capability to store, share and retrieve information and knowledge pertaining to the maintenance and administration of IMS stations;
- Platform and device independent representation of data/information (emphasis on wearable equipment);
- Integration of heterogeneous and distributed data and information sources;
- Definition of object and process repository to provide context-specific information and knowledge.

The next steps will involve the detailed technical design of the proposed framework and the implementation of a prototype to be tested with an IMS station.

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