Towards Trust-based Knowledge Management for Mobile Communities

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Abstract

Agent-mediated Knowledge Management is a promising approach to handle and maintain knowledge, especially in a distributed and mobile environment. A natural example for such an environment is a community: individuals that group together because they share the same interests. Trust is an important issue when building communities on sharing knowledge.

This paper presents our conceptual framework for trust-based knowledge management with respect to the highly distributed and mobile environment of communities. We extend an existing knowledge management system by using mobile agents that serve as dynamic delegates of the mobile user in different locations. These agents may exchange knowledge with other agents. When the user returns to a location a previously delegated agent resides, this agent reconciles the newly found knowledge with the user's knowledge base. Similar to sharing knowledge, trust plays a central role in this process since it controls the autonomous knowledge acquisition of a user's agents.

Introduction

After several years of research and application, knowledge management is still one of the most important challenges in IT infrastructures. Especially, as knowledge became a profit criterion for business, it seems to be a critical factor to organize it and make it intelligibly and ubiquitously accessible. This gets even harder because of the society becoming more and more decentralized and mobile.

A promising approach for solving distributed and mobile management tasks is the paradigm of software agents. Several current projects apply this paradigm to the area of knowledge management. Here, software agents are used for user support and personalization (CoMMA), organizing and sharing information over the WWW (DIAMS), building and maintaining Organizational Memories (FRODO), and supporting the fusion of knowledge (KRAFT). Moreover, software agents often are applied as linking layer on distributed, heterogeneous information sources to provide an overall access and a unified information presentation.

The approach of trust-based knowledge management we present here can be seen as an extension to existing mobile, agent-based and also stationary knowledge management systems: Firstly, to ease the process of finding and exchanging information and, secondly, to raise the acceptance of knowledge management by providing benefit for both the organization and the individual. Therefore, we integrate the task of knowledge management as part of an individual's natural behavior.

In the following section we will shortly describe the preceding fundamental works in the area of software agents and exchange of knowledge. In "Informal Networks and trust" we will introduce the underlying concepts adopted from the domain of social networks and our conception of trust levels. Afterwards, in "Trust-based Knowledge Management" we present our technical view on the framework to build especially regarding the organization of knowledge and the integration of trust. This is followed by a tavern scenario in "Tavern-based Knowledge Management", which will illustrate the application of our framework.

Preceding Fundamental Work

The techniques and methods used to realize our system reflecting "natural knowledge management" are developed by our preceding and current research activities. Additionally, we introduce the idea of a trust-based knowledge exchange protocol to create a knowledge management framework for mobile communities.

Thin Multi-Agent Platform

To cope with the fundamental challenges of knowledge management in mobile ad-hoc networks (MANETs) (Giordano 2002), we employ `MESH`*`Mdl`* (Herrmann 2003) as a thin mobile agent platform for mobile devices. `MESH`*`Mdl`* allows developers to implement distributed applications for ad-hoc networks as groups of cooperating mobile agents. These agents are able to move from one mobile device to another at their own will if both devices are within each other's transmission range. To deal with the dynamics of a MANET, `MESH`*`Mdl`* decouples mobile agents by introducing a *tuple space* as an asynchronous communication medium. Agents may *write tuples* (data objects) into the space and *read* or *take* (read and delete) tuples from the space. *Read* and *take* are available as blocking and non-blocking primitives. Moreover, an agent may request to be notified when a specific tuple is put into the space. Tuples are addressed associatively. They are read from the space by specifying the contents of the desired tuple partially in a so-called *template*. The space matches the existing tuples in the space with this template and returns matching tuples. On each participating device a

MESH*Mdl* runtime environment (called *engine*) is installed. Each engine runs its own space for the agents that are locally present. Agents on remote devices in transmission range have restricted access to an engine's space.

This simple communication paradigm allows agents to communicate and coordinate their actions in a very flexible way without tying them too close together. This decoupling is very important in a MANET. Agents need to be flexible enough to use their mobility in a timely fashion when a migration to another mobile device seems advantageous.

MESH*Mdl* agents are mobility-aware. Each engine presents a view of the other engines (devices) that are currently within transmission range. Thus, an agent may react directly to changes in the *neighborhood*. It may decide to migrate to a neighboring device or access its space to deposit tuples for the agents on that device.

In our System, the ability to migrate, the flexibility, the decoupling, and the asynchronous space communication are exploited by specialized mobile agents. These agents explore a mobile community and position themselves on key devices from where they can coordinate a user's knowledge management process.

Shared Knowledge

The main communication task of those specialized agents is the exchange of knowledge. Hence, we employ a technology we developed for sharing knowledge in peer-to-peer networks, called Shark (Schwotzer and Geihs, 2002).

In Shark, we applied the concepts from the knowledge representation languages TopicMaps (TopicMaps, 1999) and DAML+OIL (Harmelen, and Horrocks, 2000). In both approaches, knowledge is assumed to consist of documents, which contain arbitrary data in arbitrary formats, and a layer describing the semantics of these documents. These semantics are defined by a network of topics. By assigning documents to one or more topics, the documents' semantics (context) is given.

In a nutshell, Shark is a mobile extension to TopicMaps and the Semantic Web (SemanticWeb, 2001). It provides a peer-to-peer knowledge exchange protocol (KEP) that is similar to KQML (Finin, Weber, Wiederhold, et. al., 1994), but specialized in knowledge exchange and restricted in its functionality with respect to the limited resources on mobile devices. KEP comprises two phases: negotiation and exchange. During negotiation, the peers inform each other about the topics on which each of them is willing to receive or disseminate knowledge. Knowledge is exchanged, if one or more topics match.

Figure 1 illustrates two KEP scenarios with Bluetooth. The *Local Station* is a stationary PC with an XML TopicMap (Pepper and Moore 2001) engine. *Mobile Stations* run J2ME with a small Shark Knowledge Base. Whenever two Shark stations are close enough to establish a Bluetooth connection (about 10 meters) knowledge exchange can take place. In this example, one Mobile Station exchanges knowledge with both a Local Station and another Mobile Station.

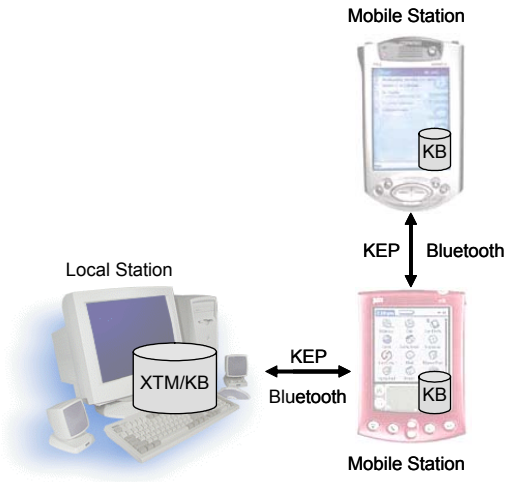

Figure 1 Two KEP scenarios with Bluetooth.

Informal Networks and Trust

Several surveys and articles have examined the existence of informal networks in organizations (e.g., Ouchi 1980, Scott 1992). The benefit of such networks for the performance of the whole organization is immense and has been extensively analyzed (e.g., Krackhardt and Hanson 1993, Wassermann 1994). The key of informal networks is a natural process in which people become a part of social groups, i.e., communities.

The general goal of such a community is to share knowledge on a common interest. Thereby, each of the members actually gains knowledge respectively, the common knowledge in that community increases by exchanging information. For each member, the community represents a collaboration platform, where both the organization and the individual benefit.

Organized Anarchy

Self-organization plays a major role in our approach since communities are *anarchic networks* of individuals who share information. Anarchic, in this context, means that associations between people do not necessarily obey the structures imposed by superordinate organizations or institutions. Although, companies usually are hierarchically structured, the information flow does not always follow these structures. The same holds for our knowledge management approach, where each individual defines his[1] own interest profile and exchange policies.

What seems contradictory at first glance does not thwart the original goal to manage knowledge. From our knowledge management point of view, individuals and communities behave similar. Both elaborate their own interests and their own rules to exchange knowledge. In sociological terms, individuals and communities are both *social*

[1] For the remainder of this paper, the male form is used for readability reasons, implying that male or female may perform the role.

groups. Thus, we support knowledge dissemination between arbitrary social groups.

In our system, knowledge management is performed by means of *agents*. Such agents act on behalf of a social group. Thus, a system user takes along his personal agent and may also carry agents of other social groups. Communication in our approach always is peer-to-peer, where peers are agents. If two individuals physically meet, with their mobile devices actually several social groups (i.e., their agents) meet to exchange knowledge.

These knowledge operating agents will self-organize a mobile knowledge network in an efficient way (see section "Using Patterns of Encounter").

Level of Trust

Related to the aspect of mobility and self-organization are the questions of finding actually needed or requested knowledge within the community and exchanging knowledge with the community members.

The aspect of trust in individuals and acquired information plays a major role for communities and, thus, for exchanging knowledge. Trust has been studied as a relationship between individuals (compare Hardin 2002). In most cases an individual as such is regarded as being trustworthy.

For knowledge exchange, we identified two dimensions of trust being necessary to provide a more granular view: *trustability* and *competence*. This viewpoint closely relates to the distinction made by Marsh (Marsh 1994). He defines three aspects (dimensions) of trust. In our approach, we merge the aspects of basic and general trust into trustability, which refers to the overall impression individuals have of each other. The third aspect of situational trust is, as we describe a knowledge management system, mapped to a specific topic or domain and describes the competence (or reputation) of an individual regarding this topic.

Hence, a level of trust reflects the combination of trustability and competence. As trust is not a binary decision, we use a continuous interval between [-1, +1] for the trust values (compare Marsh 1994). Naturally, a high level of trust in a person also renders information given by that person trustworthy, whilst a low level of trust usually does not. On the other hand, it is rather difficult to judge information given by a person who is either not trustworthy or not competent. However, such information is not necessarily incorrect. If trustability is negative, a person can be regarded as being hostile. Therefore, the most difficult case occurs when there is a lack of trustworthiness or competence. In this situation, trusted sources are needed to judge given information.

Trust-based Knowledge Management

As stated above, the environment needed for trust-based knowledge management must be able to cope with mobility and fluctuation. For these requirements, an agent-based system offers a technical platform, where mobile agents represent community members. They encapsulate a mechanism to manage topics and related information and implement trust-based exchange protocols. Equally important is the fact that the agent paradigm provides a natural way for representing the different roles a person takes depending on his current situational context.

Principle of Roles

With very few exceptions, each individual in our society is part of at least one community. Communities are, e.g., companies, sport teams, fan clubs, and cliques. The context in which a communication takes place has a strong impact on communication behavior of the participants. People usually behave differently, e.g., at business talks or when playing tennis, because they act in different roles.

The difference in communication behavior is twofold. Firstly, people filter information based on its relevance. The measurement of relevance is more or less subjective and strongly depends on the context. For instance, a weather forecast will be less interesting during working hours but more interesting at leisure time.

Secondly, communities evolve information policies that define what kind of information is allowed for dissemination, to whom, and under which circumstances. These policies are more formal and restrictive in functional differentiated groups like companies, and more informal in private social groups. Nevertheless, people follow these (formal or informal) policies when acting as member of a community.

Figure 2 illustrates the relationship of relevance, information policy, role and context. The person in the middle communicates with his environment in two different roles due to different situational contexts: business talk and leisure activity. Both, impression of relevance and communication policy depend on the person's current role. This means, he will receive and disseminate different information depending on the context.

Applying agent technology, we encapsulate the roles of communities in separate knowledge operating agents. Such agents hold the role-specific topic profile, communication policies, and trust values. The bases for these knowledge operating agents are the core components and protocols of our shared knowledge approach, the Shark technology.

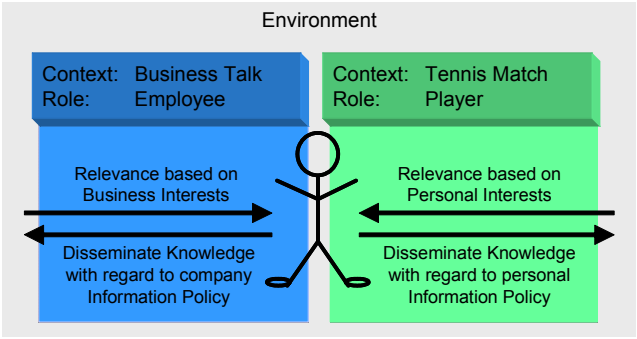

Figure 2 Relationship of relevance, information, policy, role, and context.

Organizing Knowledge in a Community

To extend Shark's scope and to enable autonomous knowledge acquirement and management, we have developed two classes of MESHMdl agents:

- *KnowGents* (knowledge agents) reside on the users' mobile devices and control their knowledge management processes. They acquire knowledge from other users and maintain his local knowledge base. To enable a user's knowledge management system to expand into the MANET of his community, the second class of mobile agents is needed.
- *DeleGents* (delegate agents) are proxies of a KnowGent (and thus, of the user) that may be sent into the community MANET. A KnowGent can autonomously take the decision to create and dispatch a new DeleGent to another device.

While KnowGents represent the classical knowledge management application component, DeleGents explore a mobile community and position themselves on key devices from where they can coordinate the users' knowledge management process.

The basic assumption behind the idea of DeleGents is that the users within a community do not move and meet other people by chance. They are situated inside a social network. They have friends and colleagues that define their social environment and thus their communities. Therefore, the people a user meets are an indication for the structure of his social network. In addition, Shark provides a sophisticated mechanism for defining and maintaining the topics that are of interest to a user.

Finally, as the following sections will explain, we can exchange information on trust among mobile users. Thus, in order to autonomously acquire and distribute knowledge on behalf of its user, a DeleGent may use *patterns of encounters* with other users, those users' topic profiles, and the accumulated trust information.

Using Patterns of Encounter. In recent years the research on complex self-organized networks resulted in some remarkable insight in the structures underlying all sorts of different networks. Among others, social networks, networks of humans and their relationships, turned out to be so-called *small worlds*. These small worlds are characterized by a low average path length between nodes (e.g. humans), a high tendency to build clusters or cliques and the formation of *hub nodes* (Barabasi 2002). This structure allows for a very efficient communication in such networks. Experiments proved that humans are quite effective at using their acquaintances (i.e. only local information) to transport a message towards an individual of which only sparse information is given. Thus, incomplete local knowledge can be used to efficiently organize the flow of knowledge.

This is exactly the idea of using *patterns of encounter*. KnowGents maintain a local model of the world they perceive through their MESHMdl engine. Upon encountering another KnowGent (mobile user) a KnowGent records certain data about the other KnowGent's user. Essentially, it registers which topics the other user is interested in. It then updates its local *encounter profile* (EP) in which it stores information, e.g., on which topics it encountered how often and for how long. *Hub users* will get in touch with many different topics while users with a more restricted range of interests are more likely to meet other people who are interested in the same topics. Thus, the inspection of the recorded profiles lets a KnowGent or a DeleGent assess which other types of users are currently around.

DeleGents on the Move. Apart from the direct interaction among KnowGents based on KEP, a KnowGent is able to create and dispatch a DeleGent when it comes across another device with an interesting EP. This DeleGent may then be equipped with subsets of the topic profile, the EP, and also the knowledge base before dispatching it to the other device. Policies may be specified beforehand to let the system decide what exactly the DeleGent carries, based, for example, on the target device's capabilities and security restrictions. Once the DeleGent is on the target device, it begins to live a life of its own. It may contact other DeleGents or KnowGents and exchange knowledge (Figure 3).

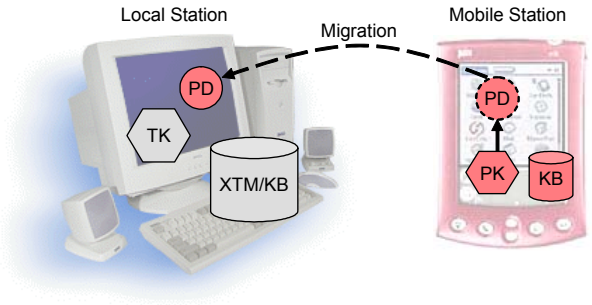

Figure 3 A mobile device encounters a stationary knowledge server. The user's personal KnowGent (PK) creates a DeleGent (PD) and dispatches it to the Local Station.

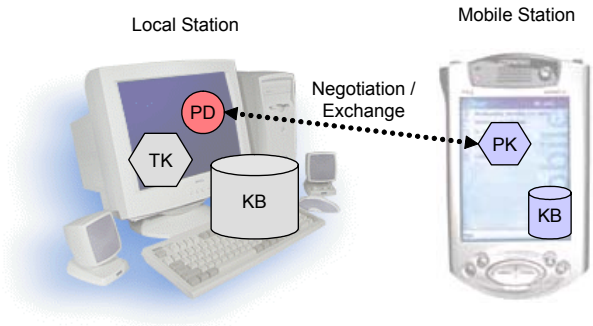

Figure 4 Another mobile user encounters the local station. The user's personal KnowGent discovers the foreign DeleGent and engages in a knowledge exchange.

Besides the EP and the topic profile, the trust information is vital to make decisions with respect to knowledge acquisition and distribution. Several DeleGents can represent a single user at different locations while he is not locally present. Based on the EPs, the user's KnowGent will choose target devices, which the user meets frequently for

dispatching DeleGents. Consequently, the KnowGent and its DeleGents will get in contact again and be able to reconcile their profiles and knowledge bases (Figure 4).

The real novelty of this approach lies in the fact that dispatching a DeleGent and thus creating a *virtual presence*, enables individuals to exchange knowledge that would otherwise not even have met. Figures 3 and 4 depict a scenario that is explained in more detail in the section on "Tavern-based Knowledge Exchange". In this scenario two users engage in a knowledge exchange indirectly without the need to meet each other. Thus, by spreading out DeleGents, a user may increase the scope of his knowledge management activities considerably. By exploiting the properties of the underlying social network via the EP, this can be done automatically. Over time, a *personal knowledge network* develops when the user's DeleGents find the best places to get in contact with the user and other community members. This network is also able to adapt by reacting to changes in the EPs and thus in the social network.

Exchanging Knowledge on Trust

For exchanging knowledge we extend the protocol defined in the Shark framework with the notion of a *level of trust* as described in the section "Level of Trust". Therefore, the KnowGent owner can specify thresholds or strategies for the trust values describing the minimal competence he requires his communication partners to have. This information is then used to decide about the subset of the topic profile that becomes visible to the partner. Gathered information then will be assessed for its true value by the level of trust.

Modeling and exchanging trust as a form of knowledge makes it possible to organize it similar to other information. This way, trust will be propagated in a community. Additionally, the trust-based exchange protocol allows automation on adjusting the level of trust for communication partners.

Initial Trust. Initially, there is a default level of trust for users one has never met before. This value depends on the individual preferences of the KnowGent owner and represents his general willingness to put trust in other individuals and in their competence (compare with Marsh 1994). Furthermore, there may be known relationships with new communication partners (e.g., members of the same association or company, negotiated or employment contracts) to such an extent, that defined levels of trust can be granted for specific topics.

Previous experience with an individual provides a basis for an initial level of trust when turning to topics not discussed before. This might be a trust value for a similar topic (e.g., first talking about tennis, then about a specific female player), so that the (adjusted) competence in the first topic can be used as starting point for the new one (Figure 5).

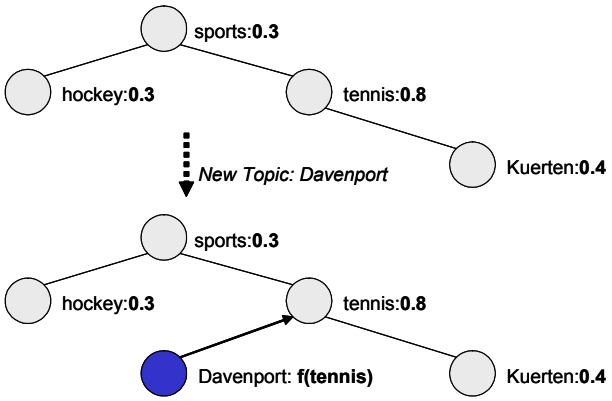

Figure 5 Competence profile for a specific communication partner and derivation for a new topic. The competence value for the new node *Davenport* will be determined by a function on its superior node *tennis.*

Adjusting Trust. To adjust the level of trust, we identified three aspects continuously influencing trustability and competence: knowledge valuation, information review, and trust exchange.

Knowledge valuation depends on the result of direct exchange. According to this result, the trust value for the competence of its provider will be adapted. This applies to information being accurate and of good quality as well as to information being incorrect and incomplete. A (manual) decision on the quality of each piece of information is needed, whether it seems accurate and appropriate.

An information review complements the knowledge evaluation. Thus, the exchanged and similar previously gathered information will be reviewed. This implies that each such piece of the information will be compared with the others taking the according providers' level of trust into account. Again, a (manual) decision on the quality of each piece of information is needed, whether it is affirming or contradicting to other information pieces. Based on the result of this review process, the level of trust of each provider is adapted. In addition, this review process implies that adjusting a trust value for a knowledge provider does not necessarily require direct interaction.

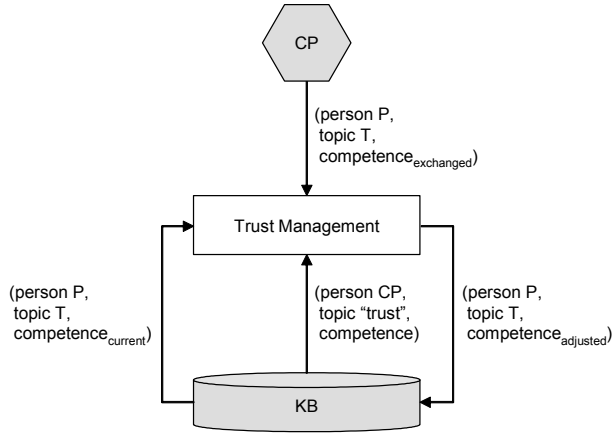

Figure 6 Adjustment of trust values: exchanging competence information with communication partner CP on a specific person (P) and topic (T).

Finally, it is possible to exchange the levels of trust. Similar to the knowledge exchange, policies decide upon what trust values to exchange and with whom. Hence, gathered trust values will be used to readjust the receiver's levels of trust for matching topics and knowledge providers. The amount of influence depends on the trust, communication partners have in each other. Hence, an adjusted trust is a function of the current trust, the exchanged trust, and the trust in the communication partner (Figure 6). The resulting trust values not only represent the experiences gained from direct knowledge exchange, but also, to a certain degree, the experiences other individuals have made with specific persons and specific topics.

Trust Propagation. The mechanism of adjusting trust as described before has a side effect regarding knowledge and trust in communities. By exchanging trust values, the level of trust will adjust and propagate throughout the social networks and especially the communities an individual belongs to. Trust propagation will self-organize a network of trust and provide an overall statistical trustworthiness based on continuous and repeated interactions with other community members. As a consequence, an individual will be able to deal with each member of the social network on an appropriate basis of propagated levels of trust since the trust network will provide him with trust information about community members he never met.

Tavern-based Knowledge Exchange

A world wide favorite hot spot for communication is a tavern. In such a place, people with various social backgrounds meet to enjoy the company of others, sharing similar interests, arguing about politics and sports. It is one of the most humanly but challenging scenarios for a mobile knowledge management system.

As stated before, in the section on "Organizing Knowledge in a Community", people usually do not meet by chance. They return to places visited before, where to find information matching their topic profile. This way, a tavern becomes a hub for different communities.

Assume the tavern called "Advantage" is well-known as a meeting point for tennis fans. Here, knowledge is shared and discussed on the latest games, single players, and of course the latest gossips on tennis stars. This scenario of physical mobility and peer-to-peer knowledge exchange already is covered by Shark, which supports the human communication as an electronic companion. So, besides talking about tennis, also images and news reports etc. might be exchanged. And, of course, other interests will be automatically shared, even though the owner of a device does not talk about them.

The agent-based approach extends Shark by introducing the notion of a virtual presence (DeleGent) in addition to the physical one. To support the communities meeting in the tavern, its publican sets up a tavern server. This server acts as a Local Station, having a knowledge base as well as a tavern KnowGent. Besides exchanging knowledge with guests, this server also allows for guests to leave a DeleGent in the tavern.

As described above, a KnowGent will decide to create a DeleGent, if the tavern server provides an interesting EP. The KnowGent will create a subset of its topic profile concerning the expected information to be gathered. The DeleGent will be equipped with this profile subset (Figure 7), an excerpt of the KnowGent's knowledge base, and information on trust and exchange policies. Finally, the DeleGent migrates to the tavern server (Figure 3) to act as virtual presence and interact with other guests (Figure 4).

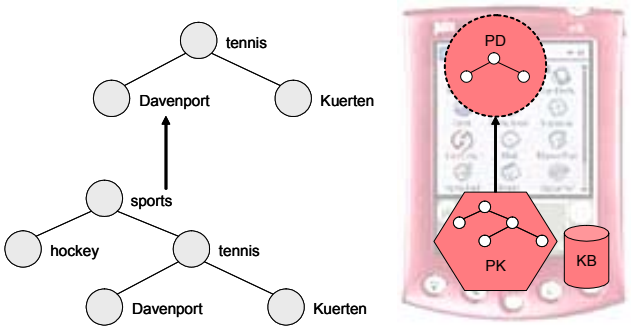

Figure 7 The personal KnowGent (PK) builds a DeleGent (PD) with a subset of its topic profile, only containing information on tennis.

By the time, the KnowGent's owner returns to the tavern, the KnowGent recognizes its DeleGent and synchronizes the knowledge on tennis, communication partners, and trust values (Figure 8). If necessary, the DeleGent will be updated with knowledge, policies, and new topics to exchange knowledge on.

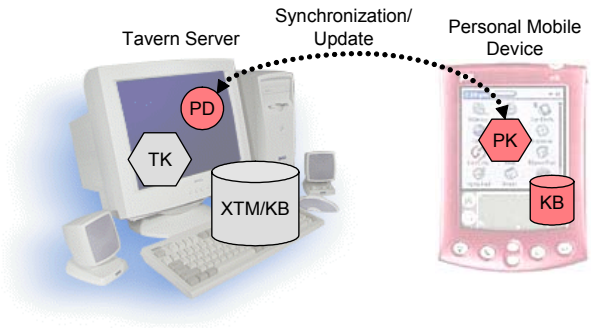

Figure 8 The personal KnowGent (PK) synchronizes with the DeleGent (PD) and updates it with the latest knowledge, i.e. topic profile subset, trust information, etc.

Not only Local Stations can carry DeleGents. If capabilities allow it, DeleGents can also migrate to Mobile Stations. This way, members of a community can carry DeleGents of each other and act as a delegate for other members. Synchronization happens each time, the KnowGent meets one of its DeleGents or two DeleGents meet. Because of this and the small world paradigm discussed before, new relevant information quickly reaches the user.

Conclusion and Outlook

Our approach of trust-based knowledge management provides the means to further automate and valuate the exchange of knowledge between individuals. It provides a framework for exchanging knowledge in a highly dynamic and mobile environment. To achieve this, we make use of the advantages introduced by the mobile agents technology, which is well-accepted for solutions in the distributed systems and management domain, and Shark, an effective technology for ad hoc knowledge exchange. We showed how DeleGents can spread out into the mobile ad hoc network of a mobile community and use trust information to serve as a virtual presence of a mobile user. By extending Shark with this agent-based approach, we enable mobile users virtually to be in several places at the same time. The sphere of knowledge acquisition can extend beyond the limits set by mobility.

Regarding the formalization of trust, several approaches have been made (e.g., Burrows, Abadi, and Needham 1990), also regarding distributed systems (e.g., Beth, Borcherding, and Klein 1994) and security issues in agent-based systems (Kagal, Finin, and Peng 2001). The use of trust is closely related to reputation management, where approaches are mainly targeting security aspects (Yu and Sing 2000), especially in decentralized systems (Aberer and Despotovic 2001). We currently work on an appropriate adaptation for trust and reputation, focusing on the exchange of knowledge.

For the scope of this paper, we left out discussions regarding an individual's communication strategy (compare Broersen, Dastani, Huang, and van der Torre 2002) and exchange policies. The concept of levels of trust is a good basis to evolve such strategies.

Furthermore, in some cases there still is a need for manual decisions. It is a matter to evaluation whether current approaches on natural language processing and document decision (e.g., Cooper and Prager 2000) at least support and at best automate the decision process.

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