Information Services to Support E-Learning in Ad-hoc Networks*

Birgitta König-Ries and Michael Klein

Institute for Program Structures and Data Organization
University of Karlsruhe
D-76128 Karlsruhe, Germany
{koenig,kleinm}@ipd.uni-karlsruhe.de
http://www.ipd.uni-karlsruhe.de/DIANE

Abstract. Mobile ad-hoc networks are a growing research topic. Much effort has been put into providing a technical basis for such networks. However, up to now, there has been very little work on how to facilitate integrated usage of the resources available in such a network. In this paper, we give an insight into our research on developing concepts to use the services of an ad-hoc net in an integrated, effective, and efficient manner. Our main focus lies on information services supporting e-learning applications.

1 Introduction

More and more people are equipped with more or less powerful mobile computers, ranging from cell phones to laptops. Over the last couple of years, research on ad-hoc networks as a means to provide technical integration of these devices has attracted a lot of attention. An ad-hoc network is a dynamic collection of mobile devices that are connected without a fixed infrastructure. In single-hop ad-hoc networks, all the devices are within radio range of each other and can communicate directly. Usually, however, interesting resources and services are spread across a wider range. What is needed then, are multi-hop ad-hoc networks, where devices can communicate with one another by "routing" information through intermediate nodes. They now become themselves part of the infrastructure. In particular, the nodes have to act as routers if needed.

So far, the technical side of ad-hoc networks has received much attention from the research community. Users, however, are not interested in network technology per se but in the services they may be able to requisition. For example, they may wish to share the information available in a network. This integrated usage of resources is quite common in fixed networks and even in infrastructure-based wireless networks. There, a lot of concepts and mechanisms exist to support integrated access to shared resources. Very little has been done, though, in the

* This work was partially funded by the *ViKar*-Project which is part of the program *Virtual University* by the state of Baden-Württemberg.

rather new research field of ad-hoc networks. Moreover, there is no straightforward adaptation of the existing solutions to networks that change their structure dynamically and have no dedicated components for building an infrastructure.

It should be quite obvious, however, that support for information sharing (or more generally for resource sharing) is needed, if these networks are to be widely used. Therefore in this paper, we develop concepts to use the resources of an ad-hoc net in an integrated, effective and efficient way. Resources are shared by offering services that allow access to them. Our special interest lies on services offering access to information. These services can be viewed as a large, highly heterogeneous, distributed information system with autonomous component systems. Our goal is to support the effective and efficient usage of these resources. On the one hand, mechanisms to use the provided resources *effectively* assure that the resources yield the desired results, i.e. that the services we find and use do what we expect them to do. On the other hand, mechanisms to use the resources *efficiently* help to gain the results in a resource-aware manner, i.e. with as little resource consumption as possible. To fulfil these demands, we outline mechanisms for service description, service discovery, service selection and efficient query processing in this paper.

2 Scenario

In this section, we introduce a scenario. The purpose of this description is twofold: First, the scenario provides a motivation for our work, explaining how we envision ad-hoc networks to be used. Second, the scenario helps to identify key issues that need to be solved in order to provide the desired functionality.

Our example user, Anna, is a computer science student. She is currently preparing for her final exam on "Information Systems". This exam covers several classes in the topic area like "Transaction Management", "Implementation of Database Systems", "Applications of Database Systems", and so on. Right now, she enjoys the nice summer weather on the patio of a coffee shop on the campus. She has brought her PDA along so that she can continue working. Before leaving home, she has downloaded the PowerPoint slides describing the two-phase commit protocol onto her PDA. After working through a few slides, she comes across an annotation mentioning a paper that explains a specific aspect in more detail. Anna tells her PDA that it should try to locate the paper somewhere and download it. Remember that Anna is not connected to a fixed network. However, her PDA forms an ad-hoc network together with other nearby computers. Some of these computers (or rather their users) will have similar interests as Anna's and might thus be able to provide the required information. Anna is lucky: her PDA finds another computer that not only possesses the paper in question but is also willing to allow Anna's PDA to download it. Unfortunately, the paper is in postscript format which her PDA is not able to display. Thus, the PDA finds a conversion service that transforms the paper into a pdf-file which can be viewed on her PDA. Over the next cup of coffee, Anna works through the paper and then returns to the original slides. Even after going through all of them, Anna is not sure that she has quite understood what 2PC is all about and feels that an example would greatly help her understanding. She asks the PDA to look for an example. It reports that the introductory course on database management provides just that. The PDA also determines that while none of the computers currently participating in the ad-hoc network has stored the example, a computer that offers access to the fixed network has just joined. Anna's PDA uses this computer's network connection to retrieve the example. By now, Anna is comfortable enough on the topic to discuss it with other students preparing for the same exam. Again, she uses her PDA to determine whether anybody is interested in joining her for a group discussion. Some fellow students, Ben and Carl, are found and a meeting is set up. At that meeting, Anna's PDA and Ben's and Carl's notebook computers form an ad-hoc network. This network is more closely integrated than the one described above. Here, the relevant information on all the participating machines is displayed on each one of the computers. Thus, Anna has transparent access to all the information available not only on her own PDA, but also on Ben's or Carl's notebook. For instance, while Anna has stored the slides of Chapter 7 of the transaction management course, Ben has stored Chapters 3 through 5 and Carl has stored Chapter 8 and 11. All six chapters are now visible on Anna's PDA and she can access any of the slides without having to know where they are stored. Should they need access to any slides that are not available locally, they can still use the search functionality described above and retrieve them from another computer in the ad-hoc network.

Let us now take a look at the requirements that need to be met in order to offer the desired functionality. Obviously, we need a possibility to spontaneously network any computers without having to rely on a fixed infrastructure. Thus, the technical basis of the system should be formed by an ad-hoc network. However, this technical basis alone is not sufficient to efficiently use the network. Additional functionality is needed that allows finding and using resources in the network. In particular, concepts are needed to address the following topics:

- **Service description.** Services need to be described so that they can be found automatically. In order to achieve this, a merely syntactic description of the service interface is not sufficient.
- **Representation of the user context.** The current context of the user, e.g. her location, the computer she is using and the state it is in, her interests and so on, plays an important role in determining which services are suitable to address her needs.
- **Service discovery.** In ad-hoc networks, the set of services that is available at any given time cannot be predetermined to be static, as the participating computers change frequently. Thus, a mechanism is needed that helps users to find the services they need.
- **Efficient usage of services.** Depending on the current structure of the network and the state of the computers that form it, strategies for efficient usage of services need to be developed.
- **Integration of services.** Often, one service alone will not be able to answer a user request. What is needed is rather a combination of different services that together offer the required functionality.

– **Motivation to offer services.** The network needs to offer some kind of incentive to participating computers to offer services. An appropriate means has to be devised.

In the following section, we will first briefly introduce the technical basis of our approach and we will then give an overview of our approach to addressing two of these problems, namely service description and service discovery. Due to space limitations, only a very brief look will be taken at the other issues.

3 Approach

The basic building blocks of our solution are *services*. A wide range of different services will be offered and used by the participants in our ad-hoc network. Services are described by service descriptions based on the developing standards in this area. These descriptions are used for a service discovery mechanism. Since ad-hoc networks do not possess any infrastructure components of their own, service discovery needs to be organized in a distributed fashion by the participating nodes. Once services have been discovered they should be used efficiently and effectively in a resource-aware manner.

3.1 Technical Basis

Figure 1 uses the sample scenario to show the basis of our system. Technically, the system is based on an ad-hoc network of different devices with widely differing capabilities (different sizes in the picture) in different states (different brightness in the picture). Computers may be active (light gray), dozing (medium gray) or

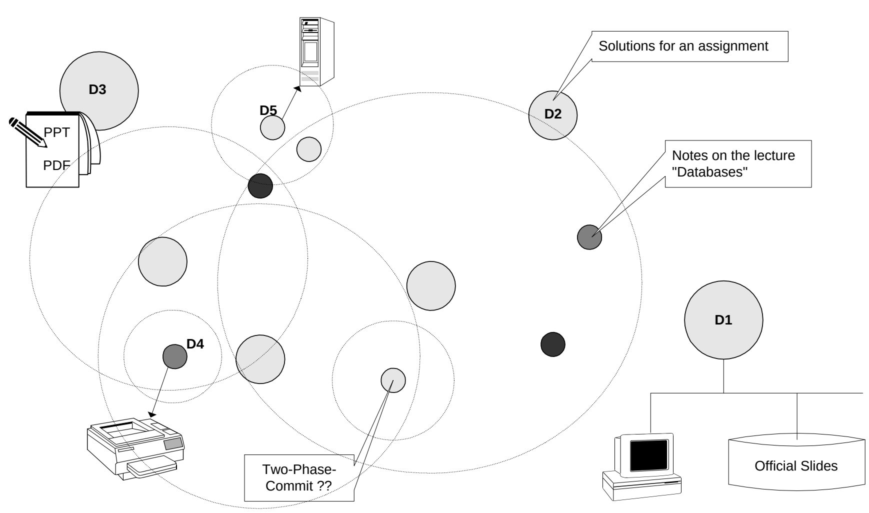

Fig. 1. Typical ad-hoc net.

turned off (dark gray). Devices can communicate directly with devices within their broadcast range (circles around nodes). Some devices like D1 can be connected to a fixed network and can mediate access to it to other devices in the ad-hoc network. If a device wishes to communicate with another device outside its broadcast range, the message has to be routed through devices between these two. The majority of the research efforts on ad-hoc networks up to now has thus been concentrated on developing appropriate routing protocols that can deal with the high dynamics of ad-hoc networks.

For our work, we are not interested in all the devices in this ad-hoc network. Rather, on a conceptual level, we assume a subnet consisting of devices with shared interests. While other devices might be used for routing purposes, we are only looking at those devices that offer services in our application domain. The figure shows a number of these devices offering different kinds of services.

3.2 Services and their Description

In our opinion, the two major prerequisites to facilitate efficient usage of an ad-hoc network is a powerful service description mechanism and an efficient service discovery and usage protocol. As a first step towards service description, consider our classification of services depicted in Figure 2.

There, two subclasses of services are identified: *DocumentConsumingServices* are services that need a document as their input and produce something else from it, e.g., a printing service that delivers a printout of a document in a specific format. *DocumentProducingServices* on the other hand, deliver documents as their output. Some services will consume a document and deliver another document. An example of this class of services is a transformation service that might require

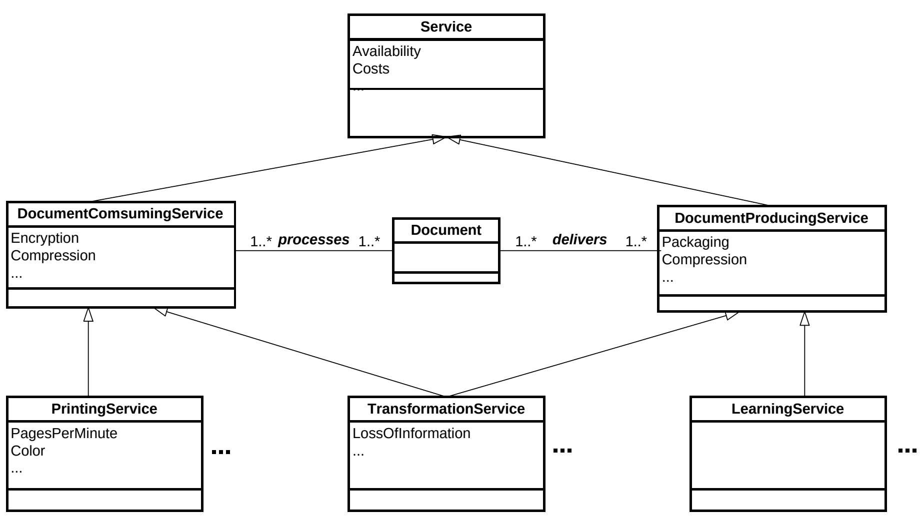

Fig. 2. Services can be subdivided in services consuming and/or producing documents.

a postscript document as input and produce a pdf-document as its output. To summarize, services process and/or deliver documents. Thus, the second central concept of our model besides services are *documents*. Our view on documents is depicted in more detail in Figure 3. Documents contain information. In our model, information is described by keywords forming ontological relationships. This means that we do not aim at describing the information contained in a document as an unstructured set of keywords, but rather as a subgraph of the underlying ontology.

In our scenario, we are particularly interested in a specific subclass of documents, *learning documents*. These documents can be subclassified into the official material of a course, external information sources and personal documents like notes, solutions to exercises, summaries that a student has written, and so on. A specific focus of our work will be on describing and finding services related to learning documents. A metadata collection based on the LOM standard [23] that provides a useful description of learning documents has been developed in the context of another project [32], and existing learning materials are already described using these metadata.

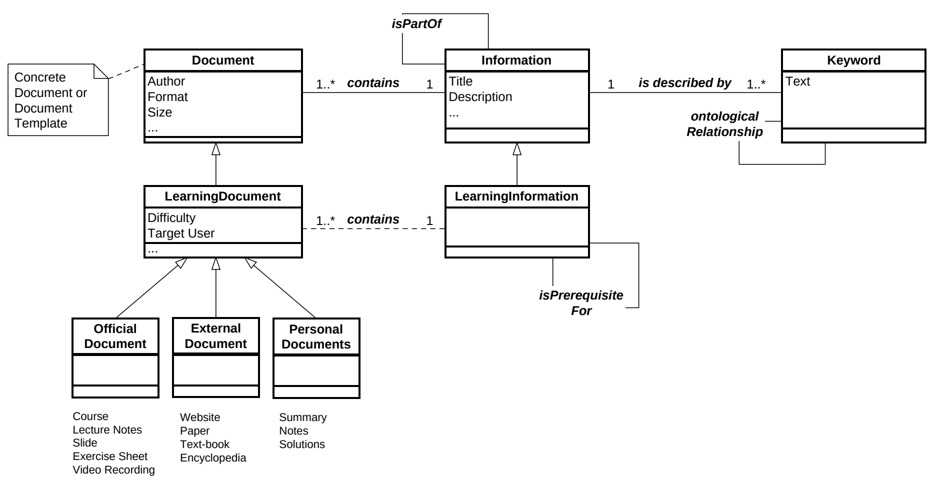

Fig. 3. A document (for example a file) always contains a piece of abstract information described by keywords in an ontological network. Learning documents can be subdivided according to their document type: official, external or personal.

Consider a PowerPoint file containing an example for the usage of the relational selection operator. If this file is stored on a computer in the ad-hoc network, the computer could offer a service to deliver this document. In this case, the service would be described by metadata for a DocumentProducingService, which consists of three parts: (1) The data about the semantical content of the offered document in the *information* part (mainly keywords from an ontology describing the selection operator and relations to other contents for example to other algebraic operators), (2) technical data about that document (as size and format) in the *document* part and (3) the characteristics of the service itself (like QoS, costs, etc.) in the *service* part.

Another service offering transformation from PowerPoint to pdf format would not be associated with a concrete document but with two document templates describing the input and output documents of the service. These templates are fully described by the *document* part of the metadata, as the service is independent from the document's semantical content. Besides the supported formats (here just PowerPoint), the template for the consumed document could for example also contain a size restriction.

More generally, services are characterized by what they do, how they do it and how they can be accessed [14]. What a service does, can be described by the input it requires, the output it produces, and the semantic relationship between the two. Therefore, our service description can be embedded into existing standardization efforts, more specific, into DAML-Services [13].

3.3 Service Discovery

In order for users to access services, they need to be able to find them. A precise service description is a necessary first step into this direction. However, service descriptions need to be accessible and comparable. Existing service discovery mechanisms rely mostly on a dedicated directory server to handle service requests by users. This approach is not feasible in an ad-hoc network. Thus, new mechanisms need to be developed that allow service discovery without dedicated infrastructure components. Service discovery by flooding as it is used by some peer-to-peer networks is not feasible either, since the enormous message overhead is not acceptable in a wireless network with limited transmission capabilities. Thus, we are developing a combination of content based routing [7, 9] and the cluster head proposal [10] to deal with this issue. In our approach, devices offering thematically coherent services are conceptually connected to *service rings*. Each ring has one or more device serving as service access point, which offers the collection of the ring's services as a whole. It is possible to build a hierarchy of rings by building rings out of such access points. Indeed, there is one ring – the so-called *world ring* – that offers all possible services. Each device aims at getting connected to an access point of this ring. Figure 4 depicts an example net. The ring on the left is formed by devices that offer a *DocumentProducingService*, more precisely a *LearningService* for documents related to the first three parts of a database course. The service access point of this ring advertises all the services offered within the ring. On the right, we have a ring specializing in printing services. Both rings are connected via the world ring, which offers all the services available in the net (that is the first three parts of the database course as well as several printing services). We use rings mainly because routing of queries to devices that offer appropriate services is very easy, we can detect message loss and always have a way back for the query answers. Moreover, rings are completely decentralized in contrast to tree or star structures.

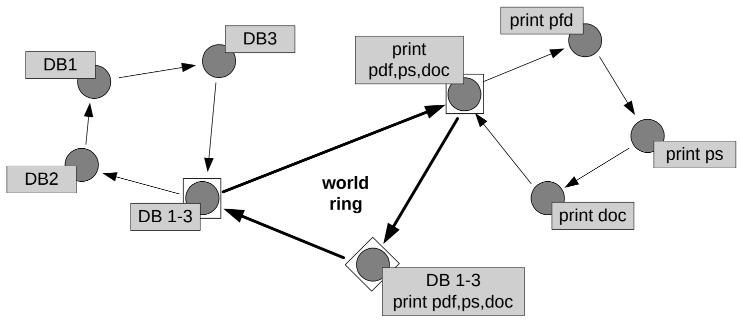

Fig. 4. Services are connected by rings. On the left, we have a ring offering *LearningServices* for lectures on "databases (DB)". It it accessible via its access point (marked with a square). On the right, printing services are combined to one ring. In the middle, the world ring offers all available services. Its access point is marked with a diamond.

3.4 Service Usage

Frequently, it will be necessary to use combinations of services instead of a single service. Possible combinations of services are service aggregation, pipelining and concatenation. With concatenation, one service delivers the input for another one. The user will be interested in the effects of both, the first and the second service. An example of a service concatenation would be a bibliographic search followed by a search for downloadable versions of the documents. Here the user will typically wish to see both the result of the bibliographic search and the list of electronically available documents. In contrast, with service pipelining, the first service also delivers the input for the second one, however, only the effect of the second service is of direct interest to the user. An example is the transformation of a postscript file provided by Service A into a pdf-file by Service B. An example of a service aggregation is the seamless integration of documents available through different services on the user's desktop.

Service delivery and service combination may depend on the current user's context. The user context is characterized by the user's current location, his level of knowledge, the device he is using and the current state of the device, e.g. with respect to battery power. Consider as an example two users trying to access a paper on a specific topic. One of the users is equipped with a laptop, the other one with a cell phone. While the first user will be able to directly download the document offered by, let's say, Service A, the second user will need an additional service that transforms the document into speech and then delivers it to his cell phone. The W3C draft on CC/PP (Composite Capability/Preference Profile) [6] forms a good basis for such a description, which we intend to use.

Mobile computers in ad-hoc networks operate on limited resources. In particular, their power supply is limited. Thus, a participant in such a network has an inherent motivation not to overuse his computer, yet alone to have somebody else use it. Thus, in order to encourage cooperation and sharing of resources, there needs to be an external motivation. Usually, this external motivation is realized by some kind of virtual currency. Whenever a computer performs a service, like delivering information, doing a computation or routing a message, it gets paid in this virtual currency and can then in turn use it to acquire the services of other devices. This looks almost like a market economy. However, in ad-hoc networks, which will be formed of devices of very different capabilities, a more sophisticated model is needed to ensure that less powerful devices, which can only perform fewer tasks, are able to participate in the network.

4 Related Work

The work on mobile ad-hoc networks evolves mainly in the context of the *IETF Working Group MANET* [24]. For the last few years, the vast majority of proposals have dealt with routing issues in ad-hoc networks. Many of them tried to transform classical routing algorithms known from infrastructure-based networks [10, 25, 28]. Especially the cluster-based routing presented in [10] is a very interesting idea, where devices are grouped to clusters and all communications between clusters are routed through dedicated cluster heads only. Other approaches deal with geographical routing mechanisms [17] and content-based routing [7, 9].

Many commercial and academic organizations have made proposals for service description. Sun's *Jini Network Technology* [19] is a JAVA based technology to offer general services in networks so that the dynamically changing participants of the net can use them. Each service is represented by an object interface, which leads to a rather inflexible description. Another approach is *JXTA Search* [20], a peer-to-peer application basing on the *JXTA project*. In JXTA Search, each (information) service is described by a query space, an XML based template for valid queries similar to namespaces, which are made publicly available by a special registration message. Due to the peer-to-peer basis, JXTA Search does not need any central server and might therefore be a suitable platform for our project. Today, one of the most popular description languages is the *Web Service Description Language (WSDL)* [34], which many commercial organizations use to offer their services. In the context of ad hoc networks, it suffers from the fact that a central server is necessary to find suitable services and only simple pattern matching queries are possible. The *Bluetooth Service Discovery Protocol* [3] and the *Universal Plug-and-Play (UPnP) Protocol* [30] have similar problems. Furthermore, they can only manage small home networks with few devices. In [18], Hodes et al. present a far more universal approach with their *Service Description Language (SDL)*. Especially user and location dependent services can be described with that. To search such services, the authors present in [11] the *Secure Service Discovery Service (SDS)*, which at present, though, is not capable to support all this functionality. Semantically richer descriptions are being developed within the research field of ontologies, especially within the *Semantic Web* [31]. One of the more important efforts centers on the *DARPA Agent Markup Language (DAML)* [12], which uses XML and RDF to describe entities and the relations between them, thus enabling the user to develop ontologies and annotate information such as service descriptions with them. Up to now, more than 150 ontologies for different topics have been created. A very interesting one among these is *DAML Services* [13], a DAML based ontology for web services. We hope to adopt some ideas out of this project. While the description languages of the Semantic Web are very powerful, no tools have been developed for them yet. The few groups (see e.g. [26]) working on the problem, concentrate on infrastructure-based networks. We thus expect a solution, which will not be applicable to ad-hoc networks directly. Another area using (service) descriptions is the research of multi-agent systems. Today, *FIPA* [15] is the most commonly used standard. Current projects aim at porting it to mobile environments [22] and to ad-hoc networks [5].

Integrating services is also a research topic. In the *Icrafter Project* [29], an interesting first approach for ad-hoc networks is given: People in a conference room can access simple infrastructure services with their mobile devices spontaneously. Tasks that should be processed together such as presenting a slide show on a beamer and turning off the lights are combined to one integrated service. From an information system's point of view, the attempt to offer integrated access to distributed services is an old topic. A large number of approaches deal with schema integration (see [2, 21] for an overview). More recently, mediator-based architectures have been investigated extensively [4, 8, 33, 35]). In the context of ad-hoc networks, we know of only two projects addressing information systems related issues. The one described in [16] attempts to find transaction models for ad-hoc networks. [27] contains a first proposal on integrated access to heterogeneous information sources in ad-hoc networks relying on an agent-based approach to address the issues.

To motivate the users of an ad-hoc net to collaborate, [1] proposes to introduce virtual coins (*nuglets*), of which each participant of the net possesses a certain amount. Every net service costs money, which is distributed among the nodes doing the work. Particularly in ad-hoc networks, the approach suffers from different problems: What is a reasonable price for a service and how can it be estimated before enlisting it? How can less powerful devices such as mobile phones use services although they are not able to offer these services by themselves? And how can the security of such a virtual currency be guaranteed in an infrastructure less environment?

To summarize, while much work has been done on routing in ad-hoc networks, we are not aware of any work that deals with sharing services in these networks. Approaches for service description, discovery and usage that have been developed in the context of fixed or structure-based wireless networks do not work well in ad-hoc networks. However, we hope being able to adapt some of the key ideas developed elsewhere to the ad-hoc context.

5 Summary and Future Work

In this paper, we propose concepts to support e-learning in ad-hoc networks. The emphasis of our work is on defining appropriate service descriptions, providing decentralized yet efficient mechanisms for service discovery and developing concepts for the seamless integration of services. Our next step will be to further refine the concepts and to evaluate them with a prototypical implementation. This prototype will support students preparing for the exam on "Information Systems". Students will be enabled to form ad-hoc nets to access material and to form discussion groups. The system will be tested in "real-life" situations. While we use e-learning as the motivating scenario for our work, we believe that the issues identified in this paper need to be addressed by any system aiming at offering access to services in an ad-hoc network. We are thus confident that the solutions we develop will be applicable to a large number of applications.

References

1. Buttyán, L.; Hubaux, J.-P.: Nuglets: a Virtual Currency to Stimulate Cooperation in Self-Organized Mobile Ad-Hoc Networks. Technical Report DSC/2001/001, Swiss Federal Institute of Technology, Lausanne, Switzerland, January 2001.
2. Batini, C.; Lenzerini, M.; Navathe, S.: A Comparative Analysis of Methodologies for Database Schema Integration. ACM Computing Surveys 18(4), 1986.
3. Bluetooth Specification Part E. Service Discovery Protocol (SDP). `http://www.bluetooth.com`
4. Beeri, C.; Milo, T.: Schemas for Integration and Translation of Structured and Semi-Structured Data, In: Proceedings of ICDT, Jerusalem, Israel, 1999.
5. M. Berger und M. Watzke: Ad-hoc FIPA Work Plan. `http://www.fipa.org/docs/wps/f-wp-00014/f-wp-00014.html`
6. W3C Working Group on Composite Capabilities, Preferences Profile. `http://www.w3.org/Mobile/CCPP/`
7. Carzaniga, A.; Deng, J.; Wolf, A.: Fast Forwarding for Content-Based Networking. Technical Report CU-CS-922-01, Department of Computer Science, University of Colorado, Colorado, USA, November 2001.
8. Chawathe, S.; Garcia-Molina, H.; Hammer, J.; Ireland, K.; Papakonstantinou, Y.; Ullman, J.; Widom, J.: The TSIMMIS Project: Integration of Heterogeneous Information Sources. In: Proceedings of the 10th Meeting of the Information Processing Society of Japan, October 1994.
9. Carzaniga, A.; Wolf, A.: Content-Based Networking: A New Communication Infrastructure. In: Proceedings of the NSF Workshop on an Infrastructure for Mobile and Wireless Systems, Scottsdale, AZ, USA, October 2001.
10. Chiang, C.; Wu, H.; Liu, W.; Gerla, M.: Routing in Clustered Multi-Hop Mobile Wireless Networks with Fading Channels. In: Proceedings of IEEE Singapore International Conference on Networks (SICON), Singapore, April 1997.
11. Czerwinski, S.; Zhao, B.; Hodes, T.; Joseph, A.; Katz, R.: An Architecture for a Secure Service Discovery Service. In: Proceedings of the 5th ACM/IEEE International Conference on Mobile Computing and Networking, Seattle, WA, USA, August 1999.
12. DARPA Agent Markup Language (DAML). `http://www.daml.org`
13. DAML Services. `http://www.daml.org/services`
14. Denker, G.; Hobbs, J.; Martin, D.; Narayanan, S.; Waldinger, R: Accessing Information and Services on the DAML-Enabled Web. In: Proceedings of the SemWeb 2001, Hongkong, China, May 2001.

15. The Foundation for Intelligent Physical Agents. http://www.fipa.org
16. Gruenwald, L.; Banik, S.: A Power-Aware Technique to Manage Real-Time Database Transactions in Mobile Ad-Hoc Networks. In: Proceedings of the 4th International Workshop on Mobility in Databases and Distributed Systems, Munich, Germany, September 2001.
17. Hubaux, J.-P.; Gross, T.; Le Boudec, J.-Y.; Vetterli, M.: Towards self-organized mobile ad-hoc networks: the Terminodes project. In: IEEE Communications Magazine, January 2001
18. Hodes, T.; Katz, R.; Servan-Schreiber, E.; Rowe, L.: Composable Ad-hoc Mobile Services for Universal Interaction. In: Proceedings of the 3rd ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), Budapest, Hungary, September 1997.
19. Sun Microsystems: Jini Network Technology. http://www.jini.org, http://www.sun.com/jini
20. JXTA Search. http://search.jxta.org
21. Kim, W.; Choi, I.; Gala, S.; Scheevel, M.: Modern Database Systems Chapter: On Resolving Schematic Heterogeneity in Multidatabase Systems, Addison Wesley, 1995.
22. Lightweight Extensible Agent Platform (LEAP). http://leap.crm-paris.com
23. IEEE LTSC Learning Objects Metadata WG Home. http://ltsc.ieee.org/wg12/index.html
24. Mobile Ad-hoc Networks (MANet) Working Group. http://www.ietf.org/html.charters/manet-charter.html
25. Murthy, S.; Garcia, J.; Aceves, L.: A Routing Protocol for Radio Packet Networks. In: ACM Mobile Networks and Communications Journal, Special Issue on Routing in Mobile Communication Networks, 1996.
26. McIlraith, S.; Son, T.; Zeng, H.: Semantic Web Services. In: IEEE Intelligent Systems, Vol. 16, No. 2., 2001; pp. 46-53.
27. Perich, F.; Avancha, S.; Joshi, A.; Yesha, Y.; Joshi, K.: Query Routing and Processing in Mobile Ad-hoc Environments. Technical Report TR-CS-01-18, University of Maryland, MD, USA, November 2001.
28. Perkins, C.; Bhagwat, P.: Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers. In: Computer Communications Review, 1994.
29. Ponnekanti, S; Lee, B.; Fox, A.; Hanrahan, P.; Winogard, T.: Icrafter: A Service Framework for Ubiquitous Computing Environments. In: Proceedings of the UBICOMP 2001, Atlanta, GA, USA, October 2001.
30. Microsoft Corporation: Universal Plug-and-Play (UPnP) Forum. http://www.upnp.org
31. SemanticWeb.org: The Semantic Web Community Portal. http://www.semanticweb.org
32. Virtueller Hochschulverband Karlsruhe (VIKAR) http://vikar.ira.uka.de
33. Wiederhold, G.: Mediators in the Architecture of Future Information Systems. IEEE Computer, 1992.
34. Web Service Description Language. http://www.w3.org/TR/wsdl
35. Yan, L.; Öszu, M ; Liu, L.: Accessing Heterogeneous Data Through Homogenization and Integration Mediators. In. Proceedings of Intl. Conference on Cooperative Information Systems (CoopIS), Kiawah Island, SC, USA, 1997.