M-Learning – Anytime Anywhere Learning in Hybrid Wireless Networks

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1. Introduction

During the last years, many mobile learning systems have been proposed and different characteristics such as data distribution and content adaptation analyzed. We want to concentrate on an other, not less important aspect of m-learning applications, namely the network architecture. In fact, the choice of the best fitting network structure may help to reduce for example communication costs, which is - for educational purposes - a crucial point. Currently most systems are based on a communication between mobile clients and a centralized server, whereas fewer applications use infrastructureless ad-hoc communication between mobile clients. We consider that a hybrid form of wireless networks may give further advantages and define this type of network as a combination of the two pure forms (client-server; ad-hoc).

This paper gives an introduction on mobile learning, by showing the importance of research in this field and a classification of m-learning in the big picture of education. A further section gives insights into hybrid wireless networks, explains the structure and points out the advantages that this type of network may provide for m-learning application.

The next section will then analyze different m-learning applications: we will first investigate on the type of network they rely on, secondly we will examine how m-learning data is distributed in that network and which form of collaboration between students is supported. A first subsection will cover applications with hybrid wireless networks, a second those applications that have a client-server structure and the last subsection analyzes an application with pure ad-hoc network.

In section 7, a comparative table gives an overview over the characteristics and differences of the previously analyzed applications.

2. Readiness for Mobile Learning

First we want to present some interesting results of a survey carried out at the University of Trento (Italy) and the Universiy of Rousse (Bulgaria) and presented 2005 in [1]. It allows us to justify the importance of research on m-learning.

The questionnaire was distributed to 600 students and was supposed to determine their attitude to mobile learning. Although 96,4% of the students had not used an m-learning system before participating at the survey, 58,5 % of the Italian and 81,6% of the Bulgarian students are keen on trying such a system. The expectations of the Italian students in m-learning systems are less high than their interest is. 57,2% of the Italian students think that mobile learning will not improve the quality of learning. This retention is partly explainable by the fact that students were asked about m-learning on cell phones. They do not consider cell phones as being well adapted for studying. Motivations for mobile learning were expectations in availability and accessibility of resources, “increased freedom in the sense of location-independence” and the integration of the learning process in their daily life. The online access of educational content and supporting educational information and the communication with other students and with teachers have been evaluated as being the most interesting services potentially offered by an application.

This survey shows, that at least until the date the questionnaire has been handed out to the students, the usage of m-learning applications - even if multiple systems have been implemented - is not widely spread. Nevertheless they see some potential in mobile learning. Students seem to be very retentive in the use of cell phones for learning. This shows that m-learning and especially the adaptation of content for mobile phones and the integration of easier-to-use devices such as laptops need to be further developed, because the learners seem to be very keen about the usage of such a system.

3. Classification of M-Learning

In order to better understand what mobile learning is, we will first place m-learning in the global scope of education, basing on the classification presented in “Transitioning from e-Learning to m-Learning: Present Issues and Future Challenges”. Georgiev, Georgieva and Trajkovski identify Traditional Learning and Distance Learning as the main building blocks of education. While Traditional Learning is characterized by face-to-face teaching in a classroom with a continuous dialogue between the teacher and the students, Distance Learning is not dependent on a special location. It allows students to learn in an asynchronous manner “at given time, at given place”. Both learning paradigms may benefit from Technical-Enhanced Learning, which is defined as “usage of special tools and technologies for increasing quality of learning”. E-learning may be seen as the intersection of Distance Learning and Technical-Enhanced Learning: it allows education via the traditional Internet where the learner may access online and offline content. Mobile learning makes use of mobile devices such as laptops, palmtops, handhelds, PDA’s, cell phones: technologies that are interconnected to allow the mobility of the users. Mobile learning should offer “complete independence of both location and time for users to use the application” (Holzinger et al, 2005). This is compliant with the definition of “nomadic users” [16]. Georgiev, Georgieva and Trajkovski define mobile learning as a subset of e-learning. The analysis of different m-learning applications, described in further details in a later section, has shown that this definition is too narrow. Different applications have been developed for supporting students during face-to-face learning in the classroom. In fact, mobile learning cannot be limited to technology-enhanced learning with distant, asynchronous communication between the teacher and the learner.

The difference between e-learning and mobile learning is, in our view, no longer limited to the further abstraction of the location and by this to the mobility of the learner but it also involves face-to-face learning. We therefore propose to broaden the definition and to consider m-learning as a subset of Technical-Enhanced Learning covering both Traditional and Distance Learning. It is important to point out that m-learning is only a subset of Technical-Enhanced learning because it makes use, as previously said, of mobile devices. Furthermore it is possible, in respect to the definition, to classify the applications according to their purpose. We identified 3 major objectives that the applications may have:

- Management of timetables, assignments, gradebooks
- Interactive participation of the learner at lecture / field experiment
- Editing and sharing of scripts and lectures notes

4. Hybrid Wireless Networks

4.1 Definition

In general, one distinguishes between 2 pure forms of wireless networks: networks with an infrastructure and self-organizing infrastructureless mobile ad-hoc networks. Infrastructured networks are in general cellular networks with fixbase stations. In the context of m-learning, the networks used rely mostly on communication links based on technologies such as GSM and UMTS. This type of links normally induces costs to the consumer. Communication in self-organizing mobile ad-hoc networks is, in general, established by technologies for which the usage of the communication is costfree, such as Bluetooth, W-LAN.

Brust, Rothkugel define hybrid wireless networks as “multi-hop wireless networks combined with a backbone network” where the term “hybrid” stands in direct relation to the fact that different communication technologies are used to create such a network.

However, an abstraction from this technology centric view seems more advantageous for m-learning applications: A wireless network may be hybrid in terms of infrastructure aspects without using different communication technologies. This means a network allowing ad-hoc communication between different mobile “client-devices” and offering a (constant) link to a not mobile device - which acts as base station/gateway to fix Internet backbone and / or server - is also hybrid, even if, for example, W-LAN is used for all communications. We define a hybrid wireless network as a network allowing simultaneously wireless communication in ad-hoc and in centralized infrastructure manner.

For our definition, the communication between a mobile and a fix node may be single-hop or multi-hop. In this point, the definition differs with the one of “hybrid ad-hoc networks” as presented in [2] The argument for [2] to focus on multi-hop communication is the fact, that less base stations are needed to cover an area. As our architecture takes also servers in account, it may be helpful, in terms of reliability, if all mobile nodes will have the possibility to directly connect to the server, in order to establish a true client-server communication. Additionally, without centering on the different technologies used, the definition should be broad enough to allow whatever technologies to establish the wireless link between a mobile node and a fix one. It is obvious that for UMTS, for example, single-hop communication is used. Therefore an architecture taking into account single-hop, but also multi-hop communication between a mobile node and a fix node will be taken in account. Mobile nodes can communicate directly with the mobile devices in their neighborhood, which is determined by the coverage range, but they may also exchange information with other nodes in the network via multi-hop communication. The fact if single- or multi-hop links are used between two mobile nodes depends on the signal strength used by the devices, which gives the responsible application the possibility to control which kind of communication should be used.

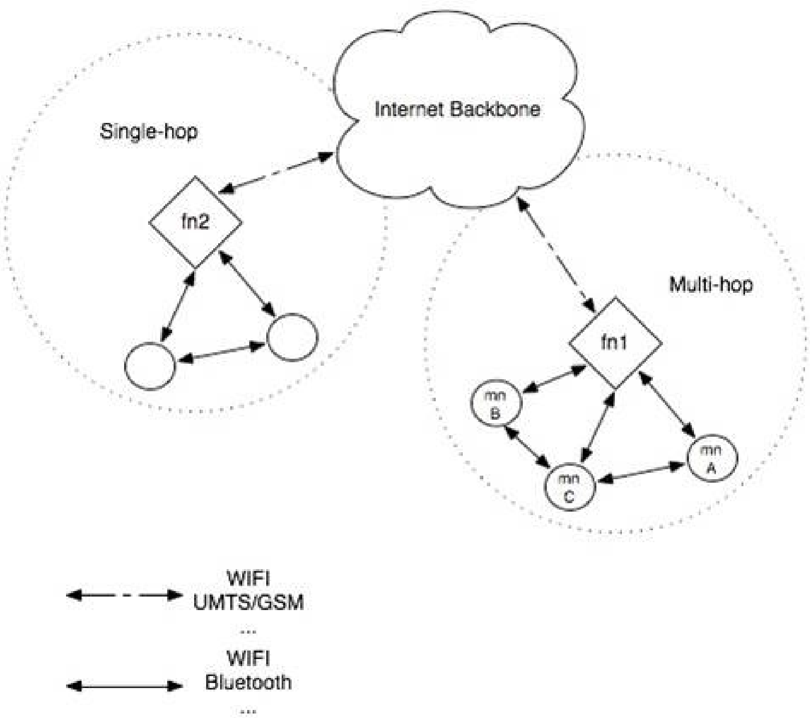

Figure 1 illustrates the aspect of single-hop and multi-hop links in the concept of a hybrid wireless network with centralized and non-centralized communication. For illustrating purposes, two servers/fix nodes have been introduced in the schema. Mobile nodes mnA and mnB are both in the coverage range of the fix node fn1. They can both communicate directly with the server fn1 but do not see each other mutually. Multi-hop ad-hoc communication will allow them to exchange information via mnC without using the infrastructure link to fn1.

4.2 Hybrid wireless networks for m-learning applications

Before analyzing which m-learning applications are using the above described network model and how they are implementing it, it seems important to justify briefly why a hybrid wireless network may be, in the view of the authors, a reasonable alternative to pure infrastructured or ad-hoc networks.

For different aspects the 2 pure network paradigms are as complementary as the concepts themselves. Weak points in self-organizing networks may be the strong ones of infrastructured networks. Hybrid wireless networks shall allow combining the advantages of both in order to build reliable and flexible mobile learning application.

For an m-learning application, the aspect of having a central authority may be very useful. It will allow managing and backup resources needed by the learners, such as scripts, lectures notes, schedules etc. on the server and permit students to access these documents via a (in general) reliable link when needed. This may allow that every learner has access to every resource and, depending on the technology used, the learner may down-, upload or share information even when no other mobile nodes are in the neighborhood (e.g. at home).

The ad-hoc communication between the mobile nodes may give an additional reliability in the sense of a peer-to-peer system. When one or more nodes, even the fix node, fail for some time, the communication may be assured, as long as a critical number of nodes are still available. If even the central authority plays an important role in the architecture, the developers of some m-learning applications may have foreseen the possibility that a group of users cooperate in an area where the infrastructured link to the fix node is not available. This cooperation can then be guaranteed via ad-hoc communication. Although there should be a possibility to synchronize afterwards with the central authority, for example by carrying the mobile device in the transmission range of the fix one.

In the context of decentralizing the definition of hybrid wireless networks away from the technology-specific character, one argument may be mentioned: for an m-learning application it is often crucial that communication is as cheap as possible. Making an abstraction from the technology used, it is possible to build up an hybrid wireless network, which purely bases on WIFI for example. If although the developers decide to use a cost-generating technology such as UMTS for building up the link to the central authority, which is still compliant with our definition, the switch between two technologies may be done by a PCMCIA card. Then although the hybrid alternative will give learners that want to reduce the amount of potentially costly communication the server the possibility to share information in the ad-hoc manner, which remains cost-free.

This is a non-exhaustive list of arguments, why we consider hybrid wireless networks as being best adapted for m-learning applications, which will justify our research on this topic.

Furthermore it should be analyzed how existing mobile learning applications have been implemented in order to benefit in an efficient manner of the advantages that hybrid wireless networks offer.

5. Applications with Hybrid Wireless Network Architecture

This section shall give an overview over the state-of-the-art of m-learning applications that have system architectures compliant with the definition focused in the section 4.1.

The search for m-learning systems based on a hybrid wireless network showed that few solutions have been implemented in this domain. Most systems use one of the two key aspects of a hybrid wireless network, either the centralized part being then known as typical client-server applications or the self-organizing element, which may be considered as pure ad-hoc network.

We want now to first discuss three applications for mobile learning that are build on a hybrid wireless network in order to see how these systems implemented this dual structure and which advantages they profit from. In a next section we will see some m-learning systems that use a pure network paradigm and analyze how a hybrid wireless network could enhance performance in aspects of reliability, accessibility, etc.

The applications, using a hybrid or a pure wireless network, will be analyzed following a same model. First the network characteristics will be discussed; is the network hybrid, which features of a hybrid wireless network are implemented, etc. We will then proceed by analyzing how data distribution is performed and check if there are special adaptations for different network types. Furthermore we will investigate on the type of collaboration of the different applications. The analysis of this aspect is justified by the fact, that a considerable number of m-learning applications have as objective to stimulate the collaboration between the learners. One distinguishes between synchronous and asynchronous collaboration. The asynchronous aspect of a collaboration tool is defined in [7] as follows: “group members need not assemble to work together”. Typical asynchronous collaboration tools are forums. Similarly [8] defines asynchronous collaboration as “a cohesive group of individuals working at different locations and at different times to solve a common task”. We will make an abstraction of the location because mobile learning is not location based anyway. In contrary to asynchronous mode, the synchronous collaboration allows members to work simultaneously on the same task. We want to point out that the definitions correspond to the time dimension of the (a)synchrony. When defining (a)synchrony of collaboration corresponding to the document dimension, one has to say, that asynchrony allows multiple versions of one document (cf. a wiki / forum) although synchrony requires a temporary lock of the resource in order to allow only one user at a time to change a document to preserve consistency. Even if this definition seems contradictory on the first sight, it is not, as the analysis of the applications will show. The aforementioned features shall be analyzed under the aspect of a (non)-hybrid wireless network.

The m-learning applications for hybrid wireless networks, that are analyzed, are DistScript, which is described in “Distributed Script – A Mobile Application for Multi-hop Ad-hoc Networks” [4], and a peer-to-peer system with server-replication presented in “Learning Communities Support by Mobile Systems Based on Peer-To-Peer Networks” [5]. In order to avoid ambiguities we will refer to the second application same as it is called in the paper: P2P and the file-sharing principle system will be referred to as peer-to-peer. The “Learning from the Starlight” project is not a true application in itself but gives interesting insights in how to deploy a hybrid wireless network for m-learning goals.

5.1 DistScript

DistScript is a collaborative m-learning tool with the objective that all the students cooperate to take notes on a lecture in order to write a single script, common to all students. The application scenario may be described as following. At the beginning of each lesson the teacher distributes the corresponding slides to those students that have subscribed to the lecture during the first lesson. Each student has the possibility to request, during the lesson, a “write token” from the teacher’s laptop. This token-system is used to insure consistency. When receiving a token, the student is granted the right to add or edit notes, to ask or to answer questions. The educational concept of DistScript is based on the assumption that “nearly every student is willing to write slide annotations for a short period of time”.

5.1.1 Network Characteristics

The DistScript Application meets the requirements of the definition of a hybrid wireless network. The central authority of the DistScript network is the token server, which is hosted on the teacher’s laptop. This device does not move (during the lecture), so it is a fix point in the network. Each student participating in the lecture context runs the token client on its mobile device. A later paragraph will explain in more detail the consistency insurance via the token service. The mobile devices of the students communicate between each other in a multi-hop ad-hoc fashion. This allows distributing notes – during the lesson - between as well students participating to the lesson inside the classroom as well as students being outside the lecture room. Outside the lecture context, students may exchange information via the en-passant pattern (described in Section 5.1.2). The communication between the teacher’s laptop and the mobile devices is also multi-hop. The use of multi-hop connections shall encourage the local exchange of data and by this the reduction of network load. A reduction of the communication signal power implicates that the application of a device will try to gather the missing slides from a neighbored device instead of inquiring immediately the teachers laptop which, by running the token server, always has the most consistent data. [4] sums up the purposes of the multi-hop communication to “(a) distribute data to all participating devices and (b) request a token from a single device”.

The Token Service, more specifically the Token Server, builds up the central authority of the network. It is used to provide consistency of the lecture notes. Additionally to the Token Server, which runs on the teacher’s laptop, each student’s mobile device hosts the Token Client. If a student wants to add or edit notes to a slide, the Token Client on the student’s device sends a request, which is a multi-hop unicast message addressed to the lecturer’s device (as this one is hosting the Token Server). If the token is granted, the server locks the annotation. The lock is based on a lease concept. This means that it is granted only during a specified period of time after which the device requesting the token has to renew it. By this, one tries to avoid that a resource stay blocked when a device currently editing an annotation fails or the communication link between that device and the server breaks down. In order to make sure that a student always edits the most recent data, the current local version is joined to the token request. The server then compares this version to its own version, which is always the newest one as the server is the only having the ability to create new versions. If the local version of the client is outdated, the server joins the most recent one to the granted token.

Additionally to the consistency feature, the teacher’s device also provides, in some terms, reliability. It is possible, for a student’s device, to request missing data from the server when the device is connected to the network via devices that do not run the application and, thus, do not provide suitable data by their own. This gives some reliability in terms of giving each student the possibility of collecting *all* necessary learning data.

For adding or editing notes it is imperative to connect to the server to maintain consistency. This means that the application may also be used outside the lecture context to simply share data but the addition and edition of notes is limited to the duration of the lesson. One could think of amplifying the client-server link by a constant connection to a UMTS network, giving students the possibility to work outside the lecture context. This would although imply costs for using the application, a fact that is bypassed for the moment by the wireless ad-hoc links.

5.1.2 Data Distribution

After this close look on the hybrid wireless network characteristics of DistScript, it seems interesting to analyze how data distribution and exchange is done.

As previously mentioned two scenarios are possible: during the lesson inside an ad-hoc network with Token Server and outside the lesson when two students with mobile device are crossing each other. The last scenario is referred to as “en-passant” communication. Two mobile devices may detect each other as potential exchange partners with the help of periodically sent beacon messages with piggybacked lecture ID. The data exchange procedure is then started with exchanging lists of missing slides, annotations and versioning information of the annotation lists, so that it is possible for the partner to calculate which data has to be exchanged.

Each requested data is sent in a single message to reduce the amount of data that is lost when the communication link fails. This precaution is important because the en-passant communication is temporarily limited as Goergen, Frey, Hutter showed in [3] where they present the testing of information dissemination during en-passant communication. Test person A started 150m away from test person B, both crossing each other in the middle of the distance. The total amount of received data was about 14 MByte for 3 evaluation processes. 10 seconds after starting the experiment, both devices got in contact for the first time while a first message could be transmitted only after second 20. During 30 seconds, the data exchange rate stayed nearly constant only dropping for the moment when both devices met. The authors give antenna interferences as explanation. After second 60 the exchange rate dropped significantly.

Considering again the DistScript application, the more reliable data distribution and exchange takes place inside the lecture context. Two aspects should be covered: newly created data is distributed using the multicast group of the lecture context, which means that only devices inscribed to the lecture are addressed. Since the multicast protocol cannot guarantee message delivery and since it is possible that students join the lesson late, it is important to retrieve missing data. As mentioned earlier, avoiding that devices request missing data instantaneously from the teacher's device can reduce the network load. Outgoing messages (e.g. beacon messages) are piggybacking data that should allow each receiving device to decide *locally* which data it should /could retrieve from which device in the neighbourhood. Piggybacked data consists of the ID of the last local available slide, the sum of all annotation list versions and other.

Additionally, a summarization of the prior lessons is piggybacked, allowing the devices to check if they have up-to-date data. When not, they may request the additional data from a nearby device, which sends only the difference between the outdated and the most recent data. The calculation of the difference relates to the modeling of all application components and the ad-hoc network itself as mobile objects, a concept that is out of scope this paper.

Replies to a request are always sent as addressed multicast messages. This means that the requesters are addressed reliably whereas other devices have the possibility to gather the message too, although without guarantee of delivery.

5.1.3 Collaboration

The collaboration triggered by DistScript corresponds to what we defined in section 5 as being a synchronous collaboration, because the application is used to write notes during the lesson when the majority of the learners are online. The Token Server assures, as previously explained, the consistency of the annotations. Although the collaboration management of DistScript has a weakness: freeloaders may profit from the system by collecting all the notes that the other students write while not giving back any additional information.

5.2 P2P

The P2P project wants to establish support for learning communities via mobile systems based on peer-to-peer networks. Learning Communities are defined in [5] “as a group of members which use network-interconnected computers to develop their individual knowledge, about a specific subject, using their personal resources, and in collaboration with the rest of the community members.”

The focus of this learning system lies on the knowledge paradigm, where each user may create his own, private knowledge, defined as being “a set of information previously analyzed about its relevance and reliance”, and making publicly available parts of this knowledge to other members of the learning community. This is referred to as being the public knowledge.

5.2.1 Network Characteristics

Same as the DistScript Application, P2P meets the definition of a hybrid wireless network given in section 4.1. As required the network consists of two major components: a central authority - the “community server” - and the infrastructureless ad-hoc network of wireless clients.

Leite, Ramirez and de Souza consider that PDAs fit best as clients for a distributed learning environment because they exceed the computation power of cell phones and remain still handier than laptops. The authors have chosen the mobile computer built-in Wi-Fi technology to interconnect the devices. The clients form a peer-to-peer network, which has two main advantages. First, by its scalability and its robustness to support frequent disconnections, it is well adapted for highly dynamic environments such as wireless networks with mobile devices in which users enter or leave frequently. Secondly a peer-to-peer network allows the learners to exchange knowledge in a decentralized manner. In fact, in the P2P system, the storage of the knowledge, its search and exchange are managed in a completely distributed fashion, the server being only used in terms of reliability and back-up as we will discuss later.

The peer-to-peer network is implemented with JXTA [6], an open-source peer-to-peer platform. This protocol set is independent of system, network and programming language because it builds up a virtual ad-hoc overlay network of decentralized peers on top of existing networks. This independency is the main advantage of using JXTA, because the overlay ad-hoc network allows connecting wired and wireless devices of whatsoever type (PC, cell phone, PDA, …). It is therefore best fitting to a project with a hybrid wireless network structure such as the P2P project. In fact, JXTA lays over both components of network: over the ad-hoc part and over the communication links between clients and the server, integrating by this way the fix server in the peer-to-peer system. One may now tend to say, that the described network is not hybrid anymore because there is one overall ad-hoc overlay. Although we justify our classification by the fact, that still only the clients will assume the functionalities of decentralized knowledge sharing in peer-to-peer fashion, while the server is assuming the role of a back-up server.

Leite, Ramirez and de Souza introduced a server in the network structure to give the system two additional characteristics: fault tolerance and robustness. Fault tolerance means that the knowledge created at the clients is back-upped at the “community server” to avoid potential loss of the data. The authors point out that “mobile computers are naturally very exposed to catastrophic faults, like breakage, theft or loss)”. Robustness is defined as being the characteristic that allows the system to “continue working even if some members leave the community”. Suppose that a user created some knowledge and then plans to leave (a disconnection that has been intended in advanced by the user, not a disconnection due to the failure of a connection link or the device itself). In the timeframe between the knowledge creation and the disconnection no other user may have requested the recently created knowledge, so the creator is the only storing the corresponding information on his PDA. After his disconnection there would be no possibility for other users to profit from this knowledge. In order to circumvent this problem, thus to make the system more robust, the user uploads, before intentionally leaving, the created content to the “community server”. During the timeframe when the user of this specific knowledge is not part of the peer-to-peer system and the content has not been distributed, the “community server” acts - for this specific type of the content - as equivalent peer in the network, meaning that it will distribute the content when asked. All requests for knowledge, which is available at any peer actively participating in the network, can only be treated inside the ad-hoc part of the network (the server will not answer such a request).

Furthermore the server acts as a knowledge repository to allow the mobile devices, which have only limited storage capacities, to store unused information at the server.

As a recapitulation one may say that the communication between clients is used to search and retrieve knowledge from others. Information exchange between the community server and the clients takes place in two directions: the mobile computers send knowledge information to the server in order to back up it, and the computer replies it when a computer wants to restore his knowledge after some problem.

5.2.2 Data distribution

The distribution of newly created knowledge takes place, in general, in the ad-hoc part of the network. Newly generated content is not broadcasted like in DistScript, but a client who needs specific knowledge has to search explicity for it. The search service is decentralized as well: “the search engine will firstly look into its own index, then look into the peers next to the user, and, finally, if it does not find an answer to the query, it will look into the peers gradually a little further from the user”. This scheme combines the index-

based search paradigm of a peer-to-peer system with some adaptations for the mobile world. The authors of [6] point out that the transmission rate of a communication link is a function of the proximity of both communication partners; therefore it is important that the search engine tries to find the nearest device hosting the searched knowledge. Additionally one may say, same as for the DistScript application, that the network load is reduced when requesting the knowledge from a device in proximity.
The knowledge retrieval via the search function is, in contrary to common peer-to-peer systems, not limited to keywords but uses semantics based on ontology. The authors highlight that ontology is the best choice for modeling knowledge.

5.2.3 Collaboration

The emphasis of the P2P m-learning system lies on the fact that this system allows the users to exchange knowledge in a collaborative way. In order to enhance collaboration, the members of the learning community must provide a small part of their resources. To ensure this purpose, two features have been implemented in a - for the user - more or less transparent way. Each client device provides to the community a small part of its own memory to store knowledge the learner does not use. This first feature is of altruistic character, whereas the second is conceived in a manner to exploit the egoistic nature of a learner in order to stimulate collaboration. A learner may cooperate more with his comates when he is rewarded for doing so. For this reason, requests for specific knowledge are served corresponding to the authorship of a user. Requests from a user that generates and edits a high amount of knowledge will be prioritized. By this way, the natural selfishness of a user is exploited to enhance collaboration whereas freeloading is prevented.

Corresponding to the definition given in section 5, collaboration in the P2P system may be classified as asynchronous. In fact, each user may generate and create knowledge whenever he wants, independent from time and from the fact that other learners are online or not. Each learner has his own repository, his own knowledge. He may extend this by copying knowledge shared by the other learners. “The editor will not be a cooperative editor; it will only allow users to exchange knowledge”. The author of a specific knowledge is the only one to change it. When he does so, the users that have knowledge based on this updated knowledge will receive a warning so that they may update their information. The collaboration may be seen, in our opinion, as the incremental acquisition of knowledge, where everybody can contribute to extend the knowledge, but no one can change information previously created by an other learner. This scheme is, to some extend, similar to the functionality of a forum. The difference to the synchronous collaboration of DistScript is in the global consistency of the created documented. In DistScript one globally consistent and unique document for a given lecture exists, whereas in P2P each user may have his own knowledge which is assembled from globally consistent parts of knowledge but which differs in the way it is assembled from the knowledge of the other users.

5.3 “Learning from Starlight”

“Learning from Starlight” is a project to “implement a new approach to classroom astrophysics integrating mobile technologies to show the real essence of Astrophysics to students”. No new application was implemented for this workshop; the importance of the project lies in showing how one can deploy a hybrid wireless network in order to favor collaboration among students for a given subject. The project will therefore not be analyzed under the aforementioned aspects of data distribution and collaboration.

The authors of [15] give an important argument for the deployment of hybrid wireless networks. In most schools in Italy – and this seems to be true for the most of the other countries – the network infrastructure is limited to an informatics laboratory sharing a single modem connection. In order to show that a hybrid wireless network could overcome this problem, allowing all the students to exchange resources and to have access to Internet, Pastore et al. set up a two-part workshop. The network setup was slightly different for each phase, but each time compliant to the definition given in section 4.1.

The first phase took place in a classical classroom, where the learners where challenged to collaborate in order to observe and analyze astrophysical phenomena of the solar system. The learners were provided with tablet and pocket PC’s. These mobile devices represent the clients of the hybrid wireless network setup and build up an ad-hoc network so that the learners can exchange notes and observations, in order to guarantee collaborative learning. The teacher’s device was equipped with a web server, assuming the role of the central authority of the hybrid network and interacting with the different clients on a client-server approach.

The second phase took place in an Astrophysical Institute. Whereas in the first phase the learners worked without having a connection to the Internet, during phase two an Internet gateway and several access points were added to the initial setup. The hybrid wireless network may now be considered as having three different types of fix elements. From the technical point of view the non-mobile access points established a fix connection to the Internet gateway, allowing the clients to access via ad-hoc mode the wired Internet. The web server of the institute assumed the responsibility of a traditional application data server with a client-server approach. The groups of learners could upload from their ad-hoc connected mobile devices to the server a final presentation of their observation.

This setup shows that it is possible to share one single Internet connection among a multitude of mobile client devices (distributed throughout a building) via a multi-hop ad-hoc network by deploying several access points.

In the next sections we will present some m-learning applications with pure wireless network forms and analyze how they could profit from a hybrid network or vice versa, which features implemented for the pure networks could give additional support for the hybrid networks.

In section 6 we will analyze m-learning applications based on client-server architectures, while section 7 will cover m-learning applications with an infrastructureless network.

6. Applications with "Pure" Architectures

6.1 Savannah

Savannah is a location-based role-play game that has been developed to teach pupils the behavior of a lion pride. The objective of the game is stated in [9] as follows: “to encourage players to understand the behavior of lions through personal experience. This directs them to learn about the resources that lions require, and to understand the daily key decisions that lions have to make in order to survive in the wild”. This educational aspect shall justify our decision for considering this game as an m-learning application. Furthermore participatory simulations, such as games for example, “appear to make very difficult ideas around ‘distributed systems’ and ‘emergent behavior’ more accessible to students” states Roschelle in [10].

Savannah has been designed as an on-the-field game: a group of pupils, each equipped with a handheld computer and a GPS receiver, are exploring a grassy field that is overlaid by a virtual savannah. The PDA models the savannah by stimulating the three senses used by lions: sound is outputted to the headphones, whereas sights and smells are represented through pictures. The group of pupils, each acting as a lion, will be jeopardized with some missions, such as marking their territory or hunting a prey. After completing their mission, the players return to the classroom (“the den”) to review their mission on an interactive whiteboard.

6.1.1 Network Characteristics

The Savannah game consists of a classic client-server architecture. The game server and the den interface assume the central authority of this architecture. The server has two main functionalities: distributing the messages related to the territory and the events (sound, sights, and smells, prey crossing the territory) to the clients and collecting/recording the positions and actions conducted by the clients. The den interface allows the real-time interaction between the tutors and the pupils via the game server during the mission and then afterwards the analysis of the mission.

Each pupil is equipped with a client, that is a PDA with Wi-Fi connection to the server. As previously mentioned the PDA models the virtual savannah and the different events that are triggered by the server and/or the tutors. When several pupils perform one action in collaboration, such as attacking a prey, each of them presses a button on the PDA interface. Only the server is, technically speaking, aware of how many lions attack the prey and is responsible to calculate the resulting effect.

There is no ad-hoc aspect in this client-server model, so that the clients have no technology-related means to directly communicate with each other. One may mention, that despite this technical limitation, the pupils may interact via gestures or by simply talking to each other, which is considered by the developers as an important educational aspect. Nevertheless an ad-hoc fashioned communication may be considered as advantage as we will discuss in section 6.1.4.

6.1.2 Data Distribution

The client-server architecture requires a nearly constant two-way communication between the clients and the server. This is a fact that may result in an important amount of data to transmit between the server and the clients and vice versa. To reduce the data transferred, the developers of Savannah decided to store the image and sound files locally on the PDA's. The server determines on the basis of three two-dimensional colormaps (representing smell, sound and sight) to trigger the clients to play/display the corresponding files.

6.1.3 Collaboration

Referring to the definitions of (a)synchronous collaboration given in section 5, the collaboration between the users of Savannah may be categorized as being synchronous. In order to complete the mission, the pupils need to collaborate by pressing the button at nearly the same time. Although it is important to notice that the collaboration triggered by Savannah differs in two points from the collaboration encouraged by the previous applications. In Savannah, collaboration is not a mean to achieve a goal, but it is a goal itself. Learning the behavior of lions means learning to collaborate. Furthermore, collaboration does not involve any technical tools, not the client or the server. The pupils cooperate primarily with gestures or by talking to each other. Decisions are taken on the basis of the events suggested by the clients and are then mapped onto to server by pushing a button on the PDA but the tools are not actively involved in the collaboration process.

6.1.4 Taking into account the hybrid aspect

We assume that integrating a hybrid network component into the Savannah architecture could have a positive effect. In their conclusion, the authors of [9] point out, that Savannah is a small-scale game, which "is still not yet suitable for a larger game rollout". In a client-server architecture, each client needs a direct connection to the server, which limits the applicability to the transmission range when using Wi-fi as connection technology. Deploying a hybrid network may reduce this limitation. First of all, the transmission range may be enlarged to some extend by the simple fact that only one PDA of the group needs to stay in the transmission range of the server gateway. This PDA would then act as gateway between the ad-hoc network created by all the PDA's in the group and the fix server. Secondly one PDA may be equipped with a communication technology such as UMTS to assure a constant link to the server and forwarding all communications over one or more hops to the other PDA's in his group. Such a network would be compliant to the type of network that Rothkugel, Brust and Ribeiro refer to as "injection network" in [11]. However it is out of scope of this paper to judge if our proposition for a change in the network architecture is still compliant with the educational intents of the Savannah game. Whereas the first suggestion refers more on the routing and technology-based aspect of a hybrid network, our second idea is more centered on the application level. An ad-hoc communication between the different PDAs of the group could allow to further enhance the communication between the game players. Such an ad-hoc feature could be exploited to display the location of the other group members on the display of the PDA and could be used by two or more players to communicate with each other without introducing more communications to the server because this kind of messages could be transmitted in ad-hoc fashion. This feature could enlarge the applicability of a similar game to a terrain where no constant line of sight is available. We are completely aware that this functionality is no longer in relation to the described Savannah application, but it may be a solution for future educational games. We also want to point out once more the necessity of a centralized server for educational purposes, since it allows the analysis of previously recorded runs of the game (see “Back in the Den” of [8])

6.2 Mobile-Eldit

Mobile Eldit is the mobile version of a language-learning platform. It has been designed for the population of the bilingual region South Tyrol in Italy and allows therefore studying the German or the Italian language. It is structured in two parts: the learner’s dictionary to learn vocabularies and a comprehension part.

6.2.1 Network Characteristics

Mobile Eldit is based on a client-server architecture, but the server is equipped with an additional feature: information about the user is collected and analyzed in order to predict the learner’s future needs. This allows the server to transmit during the connection period material that will be used during offline periods by the learner (hoarding). The Hoarding paradigm will be discussed in the following section.

6.2.2 Data Distribution

When the user is online and connected to the server, he accesses the study content through a standard web browser; but what is when the user is offline? The authors of [14] formulate this problem as follows: “Does mobile learning mean always online? Our answer to these questions is ‘No. Anytime, anywhere might be achieved also when disconnected.” This section shall analyze how the authors of [14] achieved anytime, anywhere learning when the client of the Mobile Eldit system is not connected to the server.

The solution presented by Trifonova and Ronchetti is called hoarding and defined as follows: “the process of selecting the learning materials for allowing access even during disconnected period.” The learning materials should be cached in such a way that the hit rate is maximized and the miss rate is minimized. The hit rate is defined as being the number of cached pages effectively accessed by the user divided by the total number of cached pages, whereas the miss rate indicates the percentage of pages the user wanted to access but could not, because they were not previously cached.

We will give the overall description of the hoarding paradigm, the detailed information may be found in [13] and in [14]. The decisions taken by the hoarding algorithm are mainly based on data mining, which is out of the scope of this paper.

Trifonova and Ronchetti started with a simple pruning algorithm, which was then several times refined after being tested. The browsing path of a user is modeled as a hierarchy, which allows in a first step to prune all those branches the user is not supposed to visit (based on the knowledge he gained by visiting different pages). The authors assume in [14] that sometimes a user only clicks on a page without reading it, which may lead to false assumptions on his knowledge. Therefore the algorithm will consider a page only when the user spent at least 3 minutes on it. Additionally a critical set of pages – considered as being crucial for the understanding of the current page - is created for each page and cached anyway. The authors point out: “the bigger the Critical Set is the bigger the number of satisfied request will be”. Additionally Trifonova and Ronchetti applied data mining techniques such as k-means clustering in order to group users according to their knowledge and behavior and association rules detection.

6.2.3 Collaboration

Mobile Eldit is designed to support individuals to learn German or Italian; no collaboration feature has been implemented.

6.2.4 Taking into account the hybrid aspect

Hoarding seems to be an efficient way to predict which content a user will request in the near future, based on the analysis of the content the user previously accessed. This paradigm may be especially interesting for hybrid wireless networks. Suppose, in case of the P2P application, that a student intentionally disconnects from the lecture context and leaves the university. This situation is comparable to a client-server architecture with a current offline period. The hoarding principle could be applied at the moment of the intentional disconnection to automatically determine which knowledge the student may need to revise at home and which unused knowledge may be backed-up at the server. In fact, the back-up of non-relevant data to the server has already been implemented by the developers of the P2P application. Hoarding could extend this feature by ubiquitously assisting the user in the decision which information is relevant for him and which is not.

Furthermore, we defined in section 4.2, the ad-hoc network should provide some more robustness when the link to the server breaks down. Running from time to time the hoarding algorithm and outsourcing the most important data to some client nodes might increase this fault tolerance. This means for the P2P system, that some active nodes would store altruistically some information that in general is only available at the server and might be requested in the near future by some nodes. Since the hoarding algorithm chooses only the most important data, only little storage capacity would be consumed. This leads, for the client nodes, to a tradeoff between altruistic storage capacity consumption and the advantage of continuing to work in case the connection to the server would fail for whatsoever reason.

6.3 Ubiquiz

Ubiquiz is a "Who wants to be a millionaire"-style quiz. It may be categorized as an m-learning application by itself but it might have greater use when integrated as a feature into an other m-learning application based on a hybrid wireless network to give the learners the possibility of self-assessment.

The player has to answer questions with an increasing difficulty by choosing one out of four possible answers. Furthermore he has 3 jokers that may be used in order to find the correct answer: discard 50% of the answers keeping the correct one, call a person for help, or ask the audience and display a statistic of the results.

6.3.1 Network Characteristics

The Ubiquiz application ([13]) has been implemented for infrastructureless ad-hoc networks. Each mobile device runs a copy of the application. Both, learners and teachers may create questions, which are then locally stored on the owner's device. When two or more devices meet, they will communicate via a single-hop link based on the en-passant communication pattern or form a multi-hop ad-hoc network. Inside this network, clients will then be able to exchange questions in order to create a large question pool or a user may request the help of one or more other users in order to answer a question.

The local storage of the question pool broadens the applicability of UbiQuiz, because it allows a user to play the game when not being connected to any other device running the same application.

A peer-to-peer overlay network has been implemented on top of the ad-hoc network, but because this overlay has been introduced to enhance the data distribution, it will be presented in the next section.

6.3.2 Data Distribution

Since UbiQuiz is based on a pure ad-hoc network, a different data distribution paradigm than for client-server applications needs to be used. Furthermore, the distribution paradigm needs to take into account that for educational and gameplay purposes the pool of questions should be as large and diversified as possible. This means that in a multi-hop ad-hoc network the questions should be transmitted to all the devices that are interested in the questions (or at least to the maximal possible number) and to not any other than to those interested in order to reduce the network load.

In order to determine in which type of question a device is interested in, each question belongs to a category, corresponding to a learning topic for example. Gˆrgen, Frey and Hutter propose a single-hop ad-hoc peer-to-peer overlay network to detect and address only those devices that are interested in the same category of question. This means that the application sees which devices interested in the same topic enter or leave the communication range and enables the devices to send uni-, multi- and broadcasts. The detection of entering/leaving devices is managed by periodic beaconing of the ID's of all the overlays a device is currently participating in. The beaconing period is adaptive and consists on a trade-off between detecting each device and the network load that increases with the number of beacon messages. This means that in sparse networks the beaconing interval is smaller than in dense ones. The difference between the aforementioned broadcasts and multicasts lies in the fact that for multicasts the sender takes into account the overlay structure and addresses only devices that participate in the same overlay whereas for broadcasts the receiver simply ignores messages from overlay where he is not participating in. Multicast messages are acknowledged to increase reliability.

The data dissemination is profile-based; each device determines in what sort of questions it is interested in (e.g. question difficulties). The profiles are exchanged between devices of a same overlay when a device enters the communication range or when the profile changes. The set of questions to exchange is then determined by calculating the difference of the profiles and the information send via an overlay multicast. This allows saving network bandwidth, as the information needs to be sent only once.

In addition to the overlays corresponding to categories, an altruistic overlay has been added in the peer-to-peer structure. This overlay is especially important for guaranteeing diversification. Each user stores and distributes a limited number of questions he is not interested in.

6.3.3 Collaboration

Ubiquiz is a collaboration-based m-learning game. Without collaboration, meaning the exchange of questions, the educational aspect is lost. It is therefore implicit that the users create and share questions in order to profit from the game. Selfish behavior of all the players will lead to a situation where each user owns only the set of questions, he created himself. This set will have no additional education value, since he knows the answers to the questions. Even if most of the learners will be aware of this problem and will create and share content, the application will favor freeloaders as long as only a small number of learners will act selfishly.

Collaboration in Ubiquiz has two asynchronous aspects. First of all the creation and exchange of content is asynchronous since the creation of questions is done individually by the learner. Secondly the jokers “call a friend” and “ask the audience” are asynchronous. The request of a learner triggers the response of one or more users. In the second case, all users respond without having a feedback of the others.

6.3.4 Taking into account the hybrid aspect

We will present in this section two different ways to integrate the concepts implemented in Ubiquiz into a hybrid wireless network. We do not guarantee that the goals of the following propositions do meet the aims of Ubiquiz such as they were described in [3]. The propositions shall give an idea on how an application based on a pure network form, such as Ubiquiz, could benefit from a hybrid network structure.

The difference between the network architecture used by Ubiquiz and a hybrid wireless network is the missing of a central authority in Ubiquiz. In fact, a server would introduce two additional features. The first one is robustness, as pointed out by the authors of the P2P system in [5] it would be interesting for the learners to upload those questions that have not been exchanged with any other users, to circumvent loss. As proposed in [5], the server may also act as data repository, which would be in the case of UbiQuiz an interesting feature: the questions could be stored and reused for the learners of the following semester/year. This could reduce a possible frustration of, especially, young players if they do not need to create questions before playing the game. Ad-hoc communication for m-learning applications may be considered as anarchy of the learners. The lack of a central authority may lead to mis- and abuse of the system. A central data repository would allow, in the case of UbiQuiz, the teacher to assess the questions in order to prevent misuse of the system for disseminating false information and the abuse of the system by freeloaders.

Another proposition is to enhance a system like Mobile-Eldit by an ad-hoc quiz such as Ubiquiz. This would allow the users to self-assess their knowledge by answering vocabularies or comprehension text questions. The ad-hoc component would allow the users to exchange these questions without having to access the Eldit server. One has to be aware that a system like Mobile-Eldit can only be enhanced by an ad-hoc component when there is some place where the users meet regularly. This means that it is applicable for traditional language classes but not for distance-learning classes.

7. Comparative Table

Table 1 gives an overview over the previously analyzed applications. For the hybrid networks we give the functional and non-functional responsibilities of the central authority and of the ad-hoc component of the system whereas for the client-server model we assume, that the readers know about the non-functional responsibilities of the server. Therefore only the functional responsibilities of the server are described.

<table>
<tr><th>Application</th><th>Purpose</th><th colspan="2">Network architecture</th><th>Data Distribution</th><th>Collaboration</th><th>Potential benefits from hybrid architecture</th></tr>
<tr><td rowspan="3">DistScript</td><td rowspan="3">Distributive Script Creation</td><td colspan="2">Hybrid</td><td rowspan="3">Inside lecture context:
- Multicast
- Multihop
Outside lecture context:
- En-passant communication pattern
Exchange based on mobile objects</td><td rowspan="3">- Synchronous
- Abuse by freeloaders</td><td rowspan="3"></td></tr>
<tr><td>Central Authority</td><td>Ad-hoc</td></tr>
<tr><td>- Token Server
- Data Repository
- Consistency</td><td>- Token Client
- Data dissemination</td></tr>
<tr><td rowspan="3">P2P</td><td rowspan="3">Distributed Knowledge Creation</td><td colspan="2">Hybrid</td><td rowspan="3">- No broadcast
- Explicit search for knowledge</td><td rowspan="3">- Asynchronous
- Altruistic sharing of resources
- Requests served by Authorship</td><td rowspan="3"></td></tr>
<tr><td>Central Authority</td><td>Ad-hoc</td></tr>
<tr><td>- Community Server
- Data Repository
- Fault tolerance
- Robustness</td><td>- JXTA peer-to-peer overlay
- Data storage
- Data exchange
- Decentralized search
- Scalability</td></tr>
<tr><td>Learning from Starlight</td><td>Test deployment of hybrid architecture</td><td colspan="2">Hybrid</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Savannah</td><td rowspan="2">Educational game to learn the behavior of lions</td><td colspan="2">Client-Server</td><td rowspan="2">- Sending of messages
- Sound and image files stored at clients</td><td rowspan="2">- Synchronous
- Goal itself
- Physical collaboration</td><td rowspan="2">Integrate ad-hoc component:
- Larger game scale
- Ad-hoc communication</td></tr>
<tr><td colspan="2">- Distribute messages related to territory/evens
- Recording of actions
- Real-time interaction with pupils</td></tr>
<tr><td>Mobile Eldit</td><td>Language-learning platform</td><td colspan="2">Client-Server</td><td>- Hoarding</td><td>/</td><td>Integrate hoarding into hybrid architecture:
- Ubiquitous backup
- Robustness</td></tr>
<tr><td rowspan="2">UbiQuiz</td><td rowspan="2">Educational Quiz</td><td colspan="2">Ad-hoc</td><td rowspan="2">- Profile-based
- Single hop</td><td rowspan="2">- Asynchronous
- Necessary
- Misuse to distribute false data
- Abuse by freeloaders</td><td rowspan="2">Integrate a server:
- Robustness
- Data Repository
- Central control authorithy: teacher
Integrate UbiQuiz in Mobile Eldit</td></tr>
<tr><td colspan="2">- Peer-to-peer overlay network
- Beaconing to detect entering devices</td></tr>
</table>

Table 1. Comparison of previously analyzed applications

8. Conclusion

We defined in this paper a hybrid wireless network as being a network that allows ad-hoc communication between different mobile client devices and offers a (constant) link to a not mobile device - which acts as base station/gateway to fix Internet backbone and/or server. Even though we broadened the definition from the one given by Brust, and Rothkugel by abstracting the technological aspect, we could only find little applications that match this definition. Most m-learning applications networks are still client-server based and some implementations have infrastructureless ad-hoc network architectures.

Being aware of this fact, we first studied three projects with a hybrid wireless network, and then analyzed some applications with pure network architecture in order to see how they could benefit from a hybrid one.
Hybrid wireless network combine, like we already stated in section 4.2, the advantages of ad-hoc networks and client-server architecture, since both pure paradigms are complementary.

Ad-hoc communication in a hybrid network allows the clients to communicate among each other in a cost-effective manner because the technologies commonly used for ad-hoc communication do, generally not generate provider costs. This is important since m-learning applications often provide functionalities to distributes scripts and lecture notes. A download of these resources from a server via a cost-generating link would introduce important costs. Furthermore the communication in an ad-hoc network is more similar to “real-life” collaboration than to collaboration between clients involving a server. Why not share information directly between neighbors A and B instead of transmitting the information from A to the server and from the server to B. In a multi-hop ad-hoc network the communication path between nodes A and B, indirect neighbors over C, may be shorter (and with lower cost) when A transmits information to C who then forwards the information to B than transmitting the information from A to the server and from the server C. These observations have been implemented in DistScript and P2P System, since retrieving information from the neighborhood does reduce the network load. Additionally the ad-hoc component allows users to share information even when the server is not reachable. This is very important for m-learning applications, since it allows the learners to exchange information outside the lecture context. A last argument why an ad-hoc component is useful is the scalability introduced through the decentralization of the data. Decentralizing the data distribution for large amount of data over several links is flexible and circumvents the typical bottleneck at the server.

Although, we now listed some advantages of ad-hoc networks, the server has a similar importance in network architectures, which justifies the use of hybrid wireless networks. A server introduces robustness and fault-tolerance: it allows to centralize important data and gives all the clients the possibility to access this information when the requested data can not be provided through the ad-hoc network because either no reliable link to a neighbor exists or because no neighbor has the requested information. A central authority gives also the possibility to reduce the anarchy that is introduced by the ad-hoc component. In fact, the absence of a central authority in ad-hoc networks increases the risk of fraud: users may misuse the application to disseminate incorrect data and freeloaders may abuse from the cooperative users by profiting from the content generated by the later ones without collaborating themselves.

Even though, hybrid wireless networks combines interesting advantages one has to be aware that combining two architectures may introduce some more costs (by introducing for example access points). Furthermore it is important to consider that hybrid wireless networks cannot be deployed for every m-learning application. In fact, its applicability is limited to traditional face-to-face learning that should be enhanced by mobility. In order to profit from the ad-hoc network, it is necessary that the users op the m-learning application physically meet. This means that their devices need to be in communication range.

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