Integration of Mobile Devices into Popular Peer-to-Peer Networks

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***Abstract*—Peer-to-peer content-distribution networks are nowadays highly popular among users that have stationary computers with high-bandwidth Internet connections. Mobile devices (e.g. cell phones) that are connected to the Internet via cellular-radio networks, however, could not yet be launched into this field to a satisfactory extent. Although most mobile devices have the necessary hardware resources for joining peer-to-peer content-distribution networks, they are often not able to benefit from participation, due to limitations caused by mobility. In this work, mobile devices are identified as providers of advanced mobile features and services that are usually not available to computers in stationary networks. These mobile features and services can be exchanged for services in peer-to-peer networks, turning mobile devices into valuable trading partners. Partnership schemes are set up to define the way of a fair cooperation between mobile devices and other peers. A novel peer-to-peer architecture is suggested that applies partnership schemes to a well-established peer-to-peer content-distribution network and facilitates the integration of mobile devices.**

I. Introduction

Nowadays, *peer-to-peer (P2P)* content-distribution applications are highly popular on computers in stationary networks. Also users of *mobile devices (MDs)* in cellular-radio networks (e.g. cell phones or personal digital assistants) might be interested in participating in such P2P networks. In the mobile world, contents are usually downloaded from commercial content providers (e.g. ring tones, wallpapers, games, or music). These kinds of contents could be shared among mobile users in the P2P network. However, the integration of MDs into popular P2P networks that already have large user communities is not easy to achieve.

MDs have access to the Internet, e.g. by using GPRS (General Packet Radio Service) or UMTS (Universal Mobile Telecommunications System) and mostly have enough hardware resources (e.g. CPU-power or memory) to join P2P networks. However, they are barely able to benefit from an involvement. In P2P content-distribution networks, peers have to compete for resources with other peers. MDs have different (and often limited) capabilities and properties compared to stationary computers with high-bandwidth links. Especially, mobile devices are depending on an energy efficient participation in P2P networks, to stay operational as long as possible, while being mobile. This leads to a discrimination of MDs in the competition for resources. They often need more time to download content than stationary computers, which heavily affects their battery charges.

In the research field of *mobile peer-to-peer (mobile P2P)*, several approaches have been suggested in the past (categorized and discussed in Section II) that focus on cellular-radio networks. Although some of them might be applicable to popular P2P content-distribution networks, MDs are still not widely integrated in them. As a common assumption of most approaches, MDs are considered as ”bottlenecks” that need additional support, without providing any incentive for it. This imbalance of cooperation (support has to come for free on one hand and MDs are excluded from a fair contribution on the other hand) is in conflict with the balanced cooperation paradigm of P2P networks. To solve this conflict, design principles are derived in Section II to develop a novel mobile P2P architecture. This architecture enables MDs to actively contribute mobile services (suggested in Section III) to P2P networks. Additionally, partnership schemes are defined that determine the support that has to be provided to MDs and the mobile services that have to be provided to stationary peers. This fair cooperation fosters the integration of MDs into P2P content-distribution networks. Section IV proposes a partnership-based mobile P2P architecture. A prototype of the architecture is evaluated in Section V. Section VI concludes this paper.

II. Discussion on Mobile P2P Solutions for Cellular-Radio Networks

MDs in cellular-radio networks have very different features compared to computers in stationary networks. MDs have much less CPU power, memory capacity, and storage space and can only cope with significantly less simultaneous TCP connections[1] than stationary computers. MDs are powered by batteries, limiting time and intensity of their usage. TCP connections, for instance, tend to be very energy consuming. In [1] it is described that periodic keep-alive messages of a single open connection are consuming the battery's energy within a few hours. MDs switch into dormant mode if no communication is taking place after a few seconds (e.g. 30-60 seconds). In this mode, network resources are released and energy is saved [2]. Wireless links of MDs in cellular-radio

[1] https://developer.sprint.com/show_devices.do

networks differ highly from high-bandwidth links in stationary networks. They are of variable quality and orders of magnitude slower, compared to links in stationary networks. Their quality depends on the user's movement, the number of concurrent MDs connected to a base station, and the MD's distance to a base station, for instance. Moreover, there are dead spots where wireless links break down completely, possibly leading to a change of an MD's IP address. Also, the mobile user behavior differs notably from the behavior of stationary users. Users of computers in stationary networks often prefer to be "always on", commonly having Internet flat rates. In contrast, users of MDs prefer to remain off-line most of the time to save energy in order to keep their MDs operational.

All these differences suggest that MDs in cellular-radio networks are restricted in their participation in P2P content-distribution networks and need to be supported. Therefore mobile P2P approaches can be categorized by the kind of support they provide to MDs.

A. No Support - The Straight-Forward Approach

The first category of mobile P2P approaches does not provide support for MDs within P2P networks. Instead, MDs directly join the P2P network, similar to stationary peers. To achieve this, common P2P client software is reshaped to requirements of MDs, whereas the P2P protocol itself remains unchanged. In this paper, this approach is called the *straight-forward approach*. Symella[2] is a P2P client of the Gnutella [3] P2P file-sharing network, for instance. The MD is able to download files, but uploading of files is not supported. Other examples of this category are SymTorrent[3], a client for the BitTorrent [4] P2P network or Mopiphant[4], a P2P client for the eDonkey[5] file-sharing network. The P2P software *peerboxmobile*[6] allows sharing of videos, pictures and music among users of MDs.

Generally, P2P overlays are able to cope with heterogeneity of peers and links, having different capabilities and properties. However, the joint participation of mobile and stationary devices in the same P2P content-distribution network increases the heterogeneity to an extent that may cause problems, especially for MDs. The heterogeneity affects both, peers in stationary networks and MDs. Stationary peers are affected by increased churnrates[7] and delayed downloads [5], but particularly MDs experience decreased service qualities in heterogeneous P2P networks. They find themselves in severe competitive situations with stationary computers. Often hundreds of peers do concurrently request popular downloads. A peer which is providing popular content partitions its upload bandwidth among requesting peers. A certain number of peers may be served instantly, other peers may have to wait in queues for their turn. Peers in queues are in competition with each other for resources, wanting to be served as soon as possible. MDs however, do not fare well in these competitions: 1) Among peers competing for content usually those are preferred that provide content in return (tit-for-tat principle). Due to their hardware limitations, restrictions of the wireless link, and short on-line times it is not possible for MDs to provide an equal quantity of content (or equal upload performance) as stationary computers do. 2) Due to their limited ability of managing concurrent TCP connections, MDs are not able to queue themselves in many queues simultaneously. Stationary computers are often waiting for content in up to hundreds of queues to increase the probability of being served.3) MDs in cellular-radio networks are often hidden behind firewalls. In this case, other peers are not able to establish direct communication with the MDs and additional resources of P2P network are needed to work around this issue. This often leads to penalties for firewalled peers within P2P networks. 4) If MDs go voluntarily or involuntarily off-line, e.g. because of dead spots or low battery charge, they are likely to be deleted from queues and have to restart waiting periods again.

Due to these discriminations, MDs have to wait much longer time periods for accomplishing downloads in P2P content-distribution networks than stationary computers (cf. Section V). During this time the (periodical) P2P communication prevents MDs from changing into dormant mode, which affects heavily their battery charge. The straight-forward approach is a sub-optimal solution for MDs and the following design principle is derived:

Principle 1: MDs need additional support within P2P content-distribution networks to benefit from their participation in an energy efficient way.

B. Support by P2P Protocols

Solutions of this category adhere to Principle 1 and support MDs in P2P networks. Support is provided in this case by the P2P protocol itself. To achieve this kind of support, either all peers or certain peers of a P2P network have to assist MDs. Some peers are often in a preferred position to support MDs because of having special properties (e.g. high-bandwidth links). An example of this category is the *hybrid chord protocol* [6]. It modifies the well-known *chord* protocol [7] to cope more efficiently with effects of mobility. Peers are divided into *static* nodes and *temporary* nodes. Temporary nodes (nodes with short on-line times) are relieved from storing object references, improving the overall network performance. Park et al. [8] propose a distributed mobility-management mechanism which is based on hierarchical DHTs. The mechanism differentiates between stable and unstable peers in order to handle peer mobility. Information about resource locations is stored on stable peers only. The optimal split between stable and unstable peers is further investigated in [9] and [10].

Other approaches suggest P2P networks in which certain peers are determined to support MDs by aggregating or filtering data for them. In these solutions, MDs are partly or

[2]http://symella.aut.bme.hu

[3]http://symtorrent.aut.bme.hu

[4]http://www3.informatik.uni-wuerzburg.de/staff/mopi/mopiphant.shtml

[5]http://www.overnet.org

[6]http://www.peerboxm.com

[7]In P2P parlance, the term churn denotes the stochastic process of peer turnover as occurring when peers join or leave the system.

entirely relieved from network maintenance and routing tasks. In [11] *proxy servers* are used to integrate MDs into a P2P architecture. They suggest a mobile P2P group communication application which uses a hierarchical architecture and mobile proxy nodes. The proxies facilitate resource exchange by multicast on behalf of the mobiles, thus, releasing them from being continuously on-line and from unnecessary data transmission on the uplink. The architecture and efficiency of a Gnutella-based P2P application on smart phones in cellular environment was investigated in [12]. The Gnutella protocol was modified, e.g. to get a topology, providing so called *hubs* which are required to support mobile P2P clients. In [13] *surrogate peers* support MDs and the JXME[8] project defines *relay peers* to connect mobile peers to the JXTA [14] P2P environment.

Although these solutions work well in certain mobile P2P scenarios, they are commonly not applicable to popular P2P content-distribution networks. Such networks already have a large user community that is hard to convince to accept protocol modifications or newly designed protocols, especially when peers are forced to provide additional support for MDs. Instead, other MD-supporting elements have to be added to the P2P network. Either peers within the P2P network have to provide support for MDs on a voluntary basis or a third party has to provide the support (e.g. a mobile operator). The following design principle is derived:

Principle 2: MDs have to receive support within P2P networks, without a modification of P2P protocols of large user communities.

C. Support without Generic Protocol Modifications

Solutions of this category adhere to Principle 1 and 2 and support MDs without modifying the common P2P protocols of large user communities. Instead, either peers within a network are extending their protocols to provide support for MDs on a voluntary basis, or support is provided from a third party.

An example of this category is *MobileMule*[9]. MobileMule is a project in which users support their own MD by a second, fully featured computer that has access to the P2P network. However, in this approach MDs do not really benefit from their participation in the P2P network. MDs just remotely control the second computer, not being able to download or share any content at their current location. For this reason MobileMule does not actually integrate MDs into P2P networks.

Other approaches require support by operators of cellular-radio networks. In [15] a mobile P2P file-sharing application is suggested, which uses IMS (IP Multimedia Subsystem) and SIP (Session Initiation Protocol) for resource mediation. The proposed system has a rather centralized P2P-over-SIP architecture which requires specialized protocols. It uses a P2P-application server (P2P-AS) for indexing the location of files. Another approach with operator support is the *MoPi architecture* [16][17]. In that project, additional architectural elements (a *cache peer*, a *crawling peer* and an operator driven *index server*) are placed within the operators domain to integrate MDs into the eDonkey network. MDs communicate mainly with these special components, and are separated from the outside P2P network, albeit using standard P2P protocols. Although this operator driven solution is capable of supporting MDs in P2P networks, it has its downsides. There are legal issues, because mobile users might deal with illegal content. An operator, on the other hand, is able to eavesdrop and record relayed information. In contradiction to the P2P concept, the architectural elements are centralized solutions, imposing single points of failure and scalability problems. Another downside is that this solution is based on a change (or extension) of the operator's infrastructure, which is a complex and expensive task to do.

Although adhering to Principle 1 and 2, this solution category has not achieved a widespread integration of MDs into popular P2P content-distribution networks, yet. On the one hand, the few existing solutions of this category have their downsides, as described above. On the other hand, it is difficult to introduce new solutions of this category because they depend on support for MDs that is provided voluntarily. An operator driven solution might be rewarded indirectly over time by raising utilization of the operator's infrastructure. Peer-based solutions, however, suffer from the fact that MDs are not able to provide sufficient incentives for the desired support, in terms of ordinary resource sharing. The support of MDs is costly for stationary peers in terms of resources (e.g. time, bandwidth, or disk space). Additionally, peers need to have a special software that enables the support of MDs. It is hard for MDs to receive support from other peers, without offering incentives in return. Thus, the main weakness of this solution category is the imbalance of cooperation that is in contradiction to the P2P concept. It has been shown in Section II-A that MDs are not able to provide ordinary resources to P2P networks in similar quantity and quality as stationary computers do. Therefore, other services have to be provided as incentives by MDs, according to their special abilities. As a conclusion the following design principle is derived:

Principle 3: MDs have to be enabled to contribute to P2P networks, according to their abilities.

III. Mobile Services and Partnership Schemes

In contrast to other mobile P2P approaches, this paper suggests a mobile P2P architecture that is based on all design principles, defined in Section II. When MDs are enabled to provide (sufficient) incentives to stationary peers in P2P networks, they can receive support in return. This fosters the integration of MDs into popular P2P content-distribution networks that already have a large user community. To achieve this goal, this section identifies mobile services that can be contributed to P2P networks by MDs. Then, partnership schemes are defined that describe a cooperation of MDs and stationary computers in P2P networks.

In recent years, significant technological advances in the area of mobile communications have been achieved. Most of the currently available MDs are able to process JAVA

[8]http://jxme.jxta.org
[9]http://mobil.emule-project.net

software, play music, or show videos. Some are able to receive TV or radio transmissions. They have high resolution color displays, integrated video cameras, or advanced audio systems. Sometimes MDs have GPS modules or thermal sensors. In addition, a number of wireless interfaces are available, involving WLAN, Bluetooth, or infrared. What is more, the number of available services has increased considerably over time. Besides the common telephone service, MDs are able to send SMS (Short Message Service) text messages or MMS (Multimedia Messaging Service) messages, facsimiles, or emails. Due to a unique identifier, MDs are reliably authenticated by operators. Therefore, MDs can be located, for instance, or payment/micropayment can be done by calling special service numbers[10]. Some of these features and services of MDs are not (or barely/expensively) available to computers in stationary networks, e.g. SMS text messages or MMS services, micropayment services, or services involving mobility, such as taking pictures from surroundings. This kind of services are are called *mobile services* in this paper. It is shown (in Section IV and V) that MDs have the ability to offer mobile services to stationary computers by using their JAVA environment, which turns MDs into valuable trading partners within P2P networks.

Based on mobile services, *partnership schemes* can be developed that adhere to the three principles defined in Section II. They describe the cooperation of stationary computers in P2P networks with MDs in cellular-radio networks.

A stationary peer of a P2P content-distribution network supports MDs by processing downloads on their behalf. To be able to do this, the stationary peer has to extend its P2P software. This stationary peer is called *extended peer*. MDs use specialized software to communicate with extended peers and are not part of the original P2P network. An MD schedules a download job on an extended peer and goes off-line to save energy. When the extended peer has finished the download job, the data is transferred (with highest possible throughput) to the MD. This contribution is adhering to Principle 1: MDs are completely relieved from the costly competition for resources (as described in Section II-A), because they are not part of the original P2P network. Additionally they get support in the energy efficient consumption of resources, because they are enabled to stay off-line while the extended peer processes the job and they receive the requested data with high throughput. This contribution is also adhering to Principle 2: Not all of the peers in the original P2P network have to change their P2P software. Instead only the extended peers change their software and provide support for MDs in order to consume mobile services in return.

In a first example, MDs compensate for support by providing an advertisement service to extended peers. MDs receive advertisements from extended peers and display them to the user (e.g. pictures, banners, or small videos). This mobile service might be interesting for companies that want to push advertisements to customers of cellular-radio networks. Companies could launch extended peers by themselves or sell advertisements to users of extended peers that deliver advertisements to MDs. In this case users of extended peers can be paid per advertisement that is pushed to an MD, similar to Google's popular "pay-per-click" system[11]. The contribution is defined as follows: While an extended peer transfers requested data to the MD, additionally advertisements are transferred and displayed to the user.

In a second example MDs compensate for support by providing an SMS text message service to extended peers. This mobile service might be interesting to users of P2P networks that want to send SMS text messages "for free" to cell-phone users. This kind of SMS text message service might also be interesting for companies that want to send advertisement SMS text messages to customers of cellular-radio networks. Companies could launch extended peers by themselves or pay users of extended peers that deliver text messages to MDs. The contribution is defined as follows: An extended peer processes a download on behalf of an MD. While the data is transferred to the MD, additionally text messages and phone numbers are transferred. The MDs send the received messages as SMS text messages to other MDs.

Both contributions are adhering to Principle 3: MDs are enabled to provide incentives (mobile services) to extended peers in P2P networks. The MD is able to configure its contribution (e.g. the number of SMS text messages per transferred MB of data) to fairly contribute to the P2P network. The quantity (or quality) of mobile services that MDs provide has to be sufficient to motivate stationary peers to extend their P2P software in order to support MDs.

Many other partnership schemes are possible (e.g. based on MMS services or micropayment services) and can easily be developed by using the described (or similar) mechanisms. However, the focus of this paper is not on inventing partnership schemes or evaluating their economical benefits. Instead, the focus is on illustrating that currently available technologies (e.g. cell phones in GPRS networks) can be used to apply partnership schemes to popular P2P content-distribution networks in order to foster the integration of MDs.

IV. Mobile P2P Architecture for eDonkey based on Partnership Schemes

In this section it is shown that partnership schemes (as defined in Section III) are applicable to popular content-distribution P2P networks. A novel *mobile P2P architecture* is suggested that applies partnership schemes to the eDonkey file-sharing network. eDonkey has been chosen, because it is a very popular content-distribution P2P network that has a large user community and does not explicitly support MDs in cellular-radio networks. If MDs directly join the eDonkey network, they experience disadvantages as described in Section II-A and as measured in Section V.

The proposed mobile P2P architecture encloses a eDonkey network that eDonkey network originally consists of *unmodified peers* (i.e. ordinary eDonkey peers). *Extended peers* and

[10]http://www.infin-online.de:2080/minis/mp/index.php

[11]https://adwords.google.com

MDs are new elements in the mobile P2P architecture. An extended peer is a peer that has extended its P2P software in order to provide support for MDs. Also MDs run specialized software to be able to communicate with extended peers. Extended peer and MD communicate via a *peer-to-MD interface* that is used for a client/server based communication between them. This way MDs are not directly connected to the eDonkey network. Instead, they are participating indirectly in the P2P network, using the extended peers as proxies. Figure 1 illustrates the mobile P2P architecture. It can be observed that the eDonkey network is enclosed as a component. An extended peer is shown that is on one hand a part of the eDonkey network and is on the other hand a proxy for an MD. The MD is connected to the extended peer, while being separated from the eDonkey network.

This simple structure of the mobile P2P architecture enables an easy establishment on top of the eDonkey network. A single extended peer is sufficient to instantly enable the participation of a certain number of MDs within the eDonkey network, which is limited by performance and configuration of the extended peer.

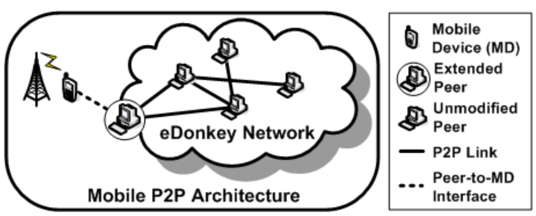

Fig. 1. Mobile P2P architecture

It is important to see that although a client/server-based communication model is used between MDs and extended peers, the proposed architecture is still a P2P-based architecture. On one hand, extended peers operate similar to unmodified peers within the P2P network. On the other hand, every MD is able to connect to every extended peer in the network (in P2P manner). P2P networks that consist of peers with different characteristics are often called *hybrid P2P networks*.

Peers of the enclosed eDonkey network that are interested in consuming mobile services extend their software to become extended peers. Extended peers are supporting MDs in an energy efficient participation within the eDonkey network by using the peer-to-MD interface. Other peers of the eDonkey network remain unmodified. Unmodified peers are not aware of the fact that new elements (extended peers and MDs) are introduced to the system.

According to the partnership schemes defined in Section III, extended peers accept download jobs from MDs. MDs schedule a download job via the peer-to-MD interface. The extended peer accepts the download job and downloads it from the eDonkey network. To perform the download, it uses the usual eDonkey protocol, similar to unmodified peers. When the extended peer has finished the download, it transfers the requested content to the MD by using the peer-to-MD interface. This transfer is initiated by the MD (the MD polls the content). Extended peers identify MDs by a pseudo-unique ID (chosen by the extended peer) to be resistant against IP address changes of MDs. To enable an energy efficient operation of MDs, the communication channel between MD and extended peer is closed, after an MD has scheduled the job. In this way, MDs are able to go off-line to save energy, while waiting until their job is finished. MDs periodically contact the extended peer via the peer-to-MD interface to see, if it has already finished the job (polling). The periodic time interval for the polling is configurable by the MD user. To achieve an energy efficient operation, the interval has to be chosen long enough to enable the MD to change into dormant mode (cf. Section II). Reasonable values may vary from a few minutes to several hours and depend on the users preferences and on the dormant-mode features of the MD.

To further improve an energy efficient support for MDs, the peer-to-MD interface should define specialized communication and application protocols to explicitly support wireless links of MDs. Varying delay or bandwidth should be considered as well as the existence of dead spots. Improved transport protocols for wireless communications are discussed in [18], for instance. The application layer protocol has to support compression and resuming functions as in the *File Transfer Protocol* [19].

MDs that are interested in downloading content from the eDonkey network have to run special software. MDs communicate with extended peers via the peer-to-MD interface. According to the partnership schemes defined in Section III, MDs offer mobile services to extended peers in order to get support. If an extended peer is interested in the offered mobile services, it accepts a download job and processes it. When it has finished the download, the content is transferred to the MD via the peer-to-MD interface. During this transfer, extended peers consume the mobile services: 1) If an advertisement service has been offered (e.g. one advertisement/MB), the extended peer sends the advertisement data to the MD before the transfer of the requested data begins. The first advertisement (e.g. a small picture) is immediately displayed to the user. 2) If an SMS text message service has been offered (e.g. one message/MB), the extended peer sends text messages together with phone numbers to the MD before the transfer of the requested data begins. The first SMS text message is immediately sent to the corresponding number.

The support of MDs by extended peers and also the contribution of mobile services to extended peers are raising legal issues that have not been considered in the proposed architecture. MDs that are supported by an extended peer may schedule jobs for morally offensive or illegal contents. Also SMS text messages (created by extended peers) that are relayed by the MDs might consist of such undesirable content. Such legal issues are not within the scope of this paper. Another issue is related to trust. MDs might receive support from extended peers without contributing mobile services and also extended peers might consume mobile services without supporting MDs. These freeriding issues have to be considered in future work.

MDs have to find extended peers (bootstrap) to be able to participate in the mobile P2P architecture. This problem is shifted to the eDonkey network, using the publish-subscriber principle. To publish their availability within the P2P network, extended peers are sharing particular *log-on* content (e.g. text files). MDs perform three steps to log on to the mobile P2P architecture: First, they bootstrap similarly to unmodified peers in the eDonkey network. Second, they look up log-on content published by extended peers and the network responds with addresses of extended peers. Third, MDs connect to one of the extended peers using the peer-to-MD interface and disconnect from the P2P network. To prevent extended peers from being overloaded, they do not publish their availability in the network if they currently have not enough resources available to support MDs. Additionally, extended peers store jobs of MDs in queues for later processing or reject MDs if too many requests arrive.

The scalability of the enclosed eDonkey network is not influenced by the proposed P2P architecture, because the newly added elements (extended peers and MDs) are not visible to the network (except from the bootstrapping process). Extended peers appear to be (very active) ordinary peers to the eDonkey network. However, a scalable cooperation between extended peers in which requests from MDs are evenly distributed, has to be further evaluated in future work.

V. Evaluation

The proposed mobile P2P architecture (cf. Section IV) was prototyped by using standard JAVA and J2ME programming language [20]. Two example partnership schemes were applied to the eDonkey network, an advertisement service and an SMS text message service, as defined in Section III. In this section, it is evaluated if the proposed architecture adheres to the three design principles described in Section II. First, it is evaluated if MDs need additional support within the eDonkey network to benefit from their participation in an energy efficient way (Principle 1). Second, it is evaluated if MDs can receive support within the eDonkey network, without a modification of the eDonkey protocol of large user communities (Principle 2). And third, it is evaluated if MDs are enabled to contribute to P2P networks (Principle 3).

In the first experiment a small isolated private eDonkey network has been set up consisting of 5 unmodified peers (ordinary eDonkey clients), 1 eDonkey index server, 1 extended peer and 1 MD. An MP3 file had to be downloaded from this network by the MD. This setup enabled reproducible measurements in an environment, where the MD was not influenced by the competition for resources with other peers.

All devices in this experiment were standard computers with Debian Linux and were interconnected via Ethernet links. All of the peers were emulated by using a typical eDonkey client software (MLDonkey client[12]. To model the restrictions of the MD, its upload was limited to 3 KB/s and the download to 6 KB/s (similar to GPRS limitations). The number of concurrent

[12]http://mldonkey.sourceforge.net

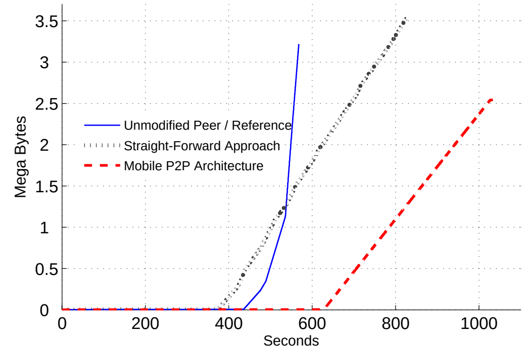

Fig. 2. Download of an MP3 in an isolated eDonkey network

TCP connections was limited to 5, according to typical MD limitations (cf. Section II). Up and download of the peer-to-MD communication were restricted to similar values (3 KB/s and 6 KB/s) and only a single TCP connection was used for this kind of communication. The periodic time interval to contact the extended peer (cf. Section IV) was set to 300 seconds. This value has to be chosen based on typical dormant-mode features of MDs (as described in Section II). The upload bandwidth of the unmodified peers and the extended peer was limited to 10 KB/s and the download bandwidth to 30 KB/s, both are typical configuration values in the eDonkey network. Further restrictions of MDs (e.g. a high latency or the existence of dead spots) are not yet considered in the experiment and will be done in future work. However it is assumed that such effects are in favor of the suggested architecture that is able to adapt to the communication behavior of MDs.

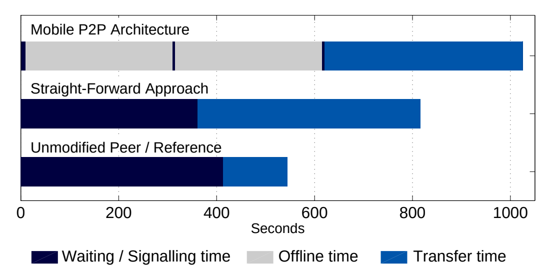

Fig. 3. On-/off-line times in an isolated eDonkey network

In this experiment, an MP3 file of approximately 2.3 MB (a typical music file) had to be downloaded from the isolated eDonkey network by the MD. A reproducible distributed download situation has been created for the MD (by distributing the file among 4 peers), before the MD started its download.In this experiment an easy situation for the MD has been created where it experiences no discrimination (as described in Section II-A). Three measurements have been done in this isolated environment. First, an unmodified peer (ordinary eDonkey peer) downloaded the MP3. Second, the MD directly downloaded the MP3 from the eDonkey network, without getting support (straight-forward approach). Third, the MD downloaded the MP3 via its peer-to-MD interface and got support by the extended peer. These measurements have been repeated several times and showed very similar results in each run. The Figures illustrating the measurements are referring to a representative single run. Figure 2 illustrates the three measurements in the isolated eDonkey network. The Y axis denotes the amount of data (in MB) transferred to the downloading peer. The transfer consists of 2.3 MB of MP3 data and a varying communication overhead of the eDonkey protocol. The X axis denotes the download times (in seconds). It can be observed that the unmodified peer started its download after about 450 seconds and finished it about 180 seconds later. The MD that directly downloaded the MP3 file from the eDonkey network (straight-forward approach) started the download after about 380 seconds. According to its slower bandwidth, the download lasted around 440 seconds. The MD that downloaded the MP3 via the peer-to-MD interface (mobile P2P architecture) started its download after about 620 seconds and needed around 410 seconds to finish it. It can be observed in Figure 2 that the MD that downloaded the MP3 directly from the eDonkey network was not discriminated at all. It started the download even earlier[13] than the unmodified peer in the illustrated case and was able to perform the download with its full available bandwidth. However, even in this competition-free environment this cannot be called an energy efficient participation of the MD. Although the download process needed around 440 seconds only, the MD had to be on-line (and consumed energy) for approximately 820 seconds to accomplish the download. Nearly half of the time it had to wait for the download to begin. This illustrates, that even in this simple scenario without discrimination of the MD, the MD is not able to energy efficiently participate in the eDonkey network. It needs to be supported, according to Principle 1.

The MD that downloaded the MP3 via the peer-to-MD interface (mobile P2P architecture) was supported by the extended peer in the isolated network. It can be observed in Figure 2 that the overall download time was the highest of the three measurements in this experiment (around 1030 seconds). However, the on-line time of the MD was considerably lower than in the other approaches. The on-line times of the different approaches are illustrated in Figure 3. The Y axis denotes three different measurements (unmodified peer, straight forward approach, and mobile P2P architecture). The X axis denotes the download times for each approach, differentiated in on-line times (signaling and transfer times) and off-line times. It can be observed that the mobile P2P architecture was the only approach where the MD was able to go off-line during the download process. At time 0 the MD contacted the extended peer to initiate the job. After that it went off-line (light grey color), waiting for the extended peer to finish. With the configured periodic time interval of 300 seconds the MD contacted the extended peer two times, to see if the job has been finished. It needed about 620 seconds to actually download the MP3. The MD was off-line most of the time during the overall process. In contrast, the other two approaches had no off-line times. Both had to wait first for the download to begin and then downloaded the file. Even in this simple discrimination-free scenario, the MD that got support from an extended peer was on-line less than half of the time than the MD that directly downloaded the MP3 from the P2P network. This illustrates that the mobile P2P architecture was able to support the MD in an energy efficient participation in the eDonkey network without changing the protocols of the other peers in the experiment (adhering to Principle 2).

In the second experiment, the scenario was repeated in the real-world eDonkey network where the MD had to compete with hundreds of peers for the content. The experimental setup consisted of 1 eDonkey index server, 1 extended peer, 1 unmodified peer, and 1 emulated MD, all of them were connected to the Internet via high-bandwidth links. Additionally, a typical cell phone (Sony Ericsson S700i) has been used. It was connected to the Internet via GPRS. The other devices and settings were similar to those in the previous experiment.

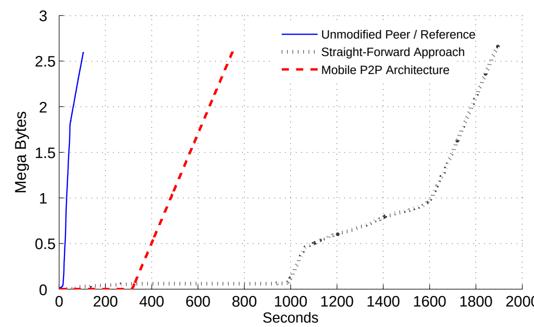

Fig. 4. Download of an MP3 in the real eDonkey network

In this experiment the MD had to download a popular MP3 file of approximately 2.3 MB size from the real-world eDonkey network (the MP3 was not hosted locally). This scenario did not reflect an easy situation for the MD anymore. A high level of competition for the popular MP3 with other peers had to be expected (as described in Section II-A). The same measurement as in the first experiment have been done. For the MD's direct download from eDonkey the MD had to be emulated again, because no eDonkey client was available for the cell phone. The Ericsson s700i downloaded the MP3 via the peer-to-MD interface. The measurements have been repeated several times and showed comparable but diverse results in each run. The following figures are referring to a single random sample of the emulated scenario. Figure 4 illustrates again the three measurements in the isolated eDonkey network. It can be observed that the unmodified peer started its download very fast and finished after around 110 seconds. The (emulated) MD that directly downloaded the MP3 file from the eDonkey network (straight-forward approach) started the download after about 980 seconds and the download lasted for around 1000 seconds. The MD that downloaded the MP3 via the peer-to-MD interface started its

[13]Due to incidental variations in the experiment, half of the times the MD started the download earlier than the unmodified peer.

download after about 320 seconds and needed another 430 seconds to finish it. It can be observed in Figure 4, that the MD that participated in the eDonkey network without support was clearly discriminated. Although the experiment was repeated several times, the MD never managed to download the file in less than 25 minutes. It had to spend most of its time by waiting for the download to begin, while being on-line and consuming energy. Also the download itself was delayed, the MD did not get the highest possible throughput due to competitions in the eDonkey network. This illustrates that in the real-world eDonkey scenario, the MD is not able to energy efficiently participate directly in the network. It needs to be supported, according to Principle 1.

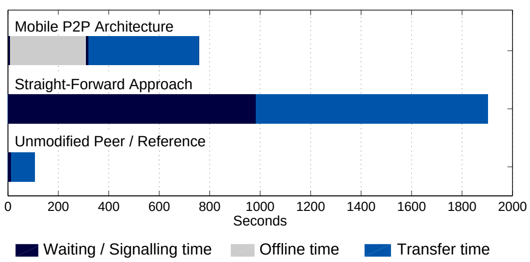

Fig. 5. On-/off-line times in the real eDonkey network

It can be observed in Figure 4 that the s700i which downloaded the MP3 via the peer-to-MD interface polled had a shorter overall download time than the direct downloading MD. Especially the on-line time of the MD was considerably lower than in the straight-forward approach. The on-line times of the different approaches are again illustrated in Figure 5. At time 0 the MD contacted the extended peer to initiate the job. After that it went off-line (light grey color), waiting for the extended peer to finish. After the configured periodic time interval of 300 seconds the MD downloaded the file. Altogether the supported MD was only on-line (and spent energy) for about 430 seconds. In contrast, the MD that directly downloaded the file spent half of its on-line time by waiting for the download to begin. Also the download itself was not performed with optimal performance in this case. This illustrates that the mobile P2P architecture was able to support the MD in an energy efficient participation within the eDonkey network, without changing the protocols of any other peer in the eDonkey network (adhering to Principle 2).

Additionally, in this experiment the provision and consumption of mobile services (advertisement service and SMS text message service) were evaluated. First, the extended peer that performed the download for the MD, pushed an advertisement (a ".png" file) to the s700i, which was displayed to the user during the MP3 transfer. Second, the SMS text message service was applied to the s700i. The extended peer that performed the download for the MD pushed text and phone number to the s700i. The text was sent as an SMS text message to the given number during the transfer of the MP3. Both contributions imposed very low overhead to the communication, because the ".png" file had less than 25 KB, of data and the SMS text message had less than 1 KB of data. The experiment has shown that the advertisement service and the SMS text message described in Section III are applicable to the eDonkey network. Therefore the proposed mobile P2P architecture adheres to Principle 3.

VI. Conclusion

An energy efficient participation of mobile devices in popular P2P content-distribution networks with large user communities has not been achieved, yet. In this paper, the imbalance of cooperation between mobile devices and stationary computers in P2P networks has been identified as a main obstacle in this context. To even out this imbalance, partnership schemes have been suggested in this paper that are based on design principles. In this partnership schemes mobile devices provide mobile services (e.g. SMS text message service or advertisement service) to stationary computers, which makes them valuable trading partners within P2P networks. A mobile P2P architecture has been proposed that implements this partnership schemes by extending the popular eDonkey network. An evaluation illustrated that the energy efficient participation of mobile devices in P2P networks can be supported by stationary computers. It also illustrated that mobile services can be provided to stationary computers in return, by using currently available technologies.

In future work the scalability of the suggested solution will be further evaluated (e.g. how many mobile devices can be served by a single extended peer or how many extended peers are needed to integrate a sufficient number of mobile devices into a peer-to-peer network). Furthermore, security issues have to be evaluated in future work to make the proposed solution applicable to real-world peer-to-peer networks. Mechanisms have to be found that prevent the misuse of partnership schemes and ensure the appropriate delivery of mobile services as well as the delivery of peer-to-peer content. Also legal issues have not yet been considered in the proposed architecture.

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