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P2P-based Network and Service Operation for the Emerging Future Internet

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Advances of Mobile P2P Services

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1 Introduction

Peer-to-Peer (P2P) computing is a networking and distributed computing paradigm which has become highly popular in the wired Internet. It permits users or entities to share their resources, e.g. bandwidth, files or CPU cycles, by direct, symmetric interaction. *P2P services* are end-user applications and P2P-based networking fundamentals. These services form *overlays* on application level, representing logical relationships among peers.
With the advances in wireless data communication technology, the increasing number of mobile users, and their desire for ubiquitous communication, P2P has drawn attention to be applied in wireless and mobile networks. *Mobile P2P services* are aiming to transfer the advantages of P2P services (server-less operation, edge services, self-organization) into the wireless domain. However, the special characteristics of mobile environments such as limited throughput, lossy channel, diversity of network architectures, and in particular the user mobility, are expected to have significant impact on the functioning and performance of these services.
This article investigates how the P2P paradigm can be applied to wireless and mobile networks. In particular, it discusses the impact of device mobility on mobile P2P services and the selection of mobility management mechanisms for these systems. Section 2 derives the constraints of mobile networks on P2P systems. Section 3 gives an overview on popular P2P mechanisms and P2P applications and provides definitions of P2P and mobile P2P services. In Section 4 selected mobile P2P projects are briefly reviewed, and in Section 5 an exemplary mobile P2P file sharing architecture for infrastructure-based mobile networks is discussed. Section 6 concludes this article with brief summary.

2 Mobile Requirements

The term *mobility* refers to a variety of wireless systems which have different features and requirements on mobile P2P services. These features comprise the radio communication

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characteristics, e.g. link capacity, lossy channel, energy consumption, the system architecture (infrastructure-based/infrastructure-less), and the *essential network services* such as addressing, routing, and in particular, mobility management. Next, a brief review of mobile and wireless networks regarding these features is given and the constraints to mobile P2P services are derived. This discussion should also allow to evaluate and characterize existing mobile P2P solutions within respect to these features.

2.1 Mobile Architectures

Infrastructure-based Systems

Infrastructure-based wireless networks are characterized by the use of dedicated elements such as attachment points, routers, and registers. They implement essential network services in a centralized way.
Cellular mobile networks are designed for enabling voice communication everywhere. They are highly hierarchically organized and support accountable services, nation-wide roaming and a high degree of mobility. Current 2.5G/3G cellular networks have been extended for providing high-speed data services. The air interface capacity is asymmetrically split between up- and downlink and the typical downlink data rates differ significantly between the technologies, cf. Table 1. GPRS/UMTS networks implement a indirect routing approach, cf. Section 2.2, due to their hierarchical infrastructure. All IP traffic is routed through the *Gateway GPRS Support Nodes (GGSNs)*. This concept is *operator-centric* and it can hardly be exploited by *edge-based* services.
Wireless access systems such as WLAN (IEEE 802.11x in base station mode) or WiMAX (IEEE 802.16x) are high bandwidth feeder networks to the Internet, cf. Table 1. Users can move and connect to different attachment points. A seamless mobility on network layer, i.e. without disruption of IP connectivity, is only possible with enhancements like *MobileIP*.

Infrastructure-less Systems

In infrastructure-less wireless networks, no support for connectivity in terms of dedicated hardware or software is available. This feature has to be provided by the communicating elements in a *self-organizing way*.
Mobile ad-hoc networks (MANETs), such as Bluetooth or WLAN in point-to-point mode, are self-organizing transport networks of mobile routers and associated hosts. Adjacent nodes communicate via direct (peer-to-peer) radio links which have typical data rates in the order of hundreds of Kbps or a few Mbps, cf. Table 1. MANET topologies are less hierarchical and may change rapidly. Nodes are allowed to move arbitrarily around. Mobility management is embedded in the MANET routing protocols. MANET hosts have to handle the address assignment and distribution of routing information by themselves. Minimal configuration and quick deployment features make these networks suitable for a spontaneous setup and mobile applications.
Pervasive/Ubiquitous Computing is related to *application architectures* complementing the above mentioned radio network technologies. The concept aims at seamless services ev-

Class	Technology	Typical Data Rates (Downlink)	Addressing	Routing	Mobility Management
Cellular	GPRS	53.6kbps	foreign address (not visible), home address (permanent, visible)	indirect	by infrastructure elements
	UMTS (today)	386kbps			
	HSDPA (future UMTS)	8-10Mbps			
Wireless Access (enhanced by MobileIP)	WLAN (IEEE 802.11x, basestation mode)	54Mbps (IEEE 802.11g)	foreign address (not visible), home address (permanent, visible)	indirect	
	WiMAX (IEEE 802.16x)	75Mbps (IEEE 802.16a)			
MANET	Bluetooth Version 2	2.1Mbps	host-based (local)	host-based (local)	distributed, protocol embedded
	WLAN (IEEE 802.11x, point-to-point mode)	54Mbps (IEEE 802.11g)			
Ubiquitous Computing	not applicable	not applicable	application-based	application level	not determined

Table 1: Characteristics of Wireless Technologies

erywhere and at any time. It permits, among other features, to transfer the context of an application beyond a single connectivity session, thus enabling *application-level mobility*. Applications coordinate their own addressing scheme and perform routing independently of the transport network, cf. Table 1. Pervasive/Ubiquitous Computing services do not focus on a tit-for-tat provisioning of resources as typically proposed by P2P services.

2.2 Mobile System Constraints on P2P Services

The functioning of mobile P2P services is determined by the main features of wireless systems: the *mobility management* and the *radio communication*.

Mobility Management Mechanisms

Mobility management aims at continuous and transparent connectivity of mobile entities. The complexity of the mechanisms depends on the degree of the users' mobility on supported network level. User mobility ranges from *low mobility*, i.e. moving within the coverage area of a single wireless access system (*low mobility*), over *medium mobility*, i.e. the users switch down connections and reconnect from another access point, to *high mobility* where seamless connectivity exists throughout the movement of users through multiple access points.
Mobility management can be implemented via *indirect routing* or *direct routing*. In the indirect routing mode, an entity (e.g. the home agent) takes care of the permanent address of a mobile, keeps track of the foreign address, i.e. the address at the current location of the mobile, and forwards the data to this address. In the direct mode, the correspondent receives the node's current address. Hence, it can contact the mobile device directly, avoiding triangular routing.

Constraints on P2P by Types of Wireless Network Structures

Infrastructure-based wireless networks typically apply the indirect routing approach. This concept, however, suffers from the *triangle routing problem*, that means all data has to be routed through a central entity. If a mobile P2P application is using this kind of network, it may occur that the overlay structure of the P2P system does not match with the data path in the wireless system, thus degrading performance. Therefore, P2P applications can benefit *infrastructure awareness*. That means they have to be able to adapt to the given transport infrastructure. In addition, interfacing with mobility information from mobility management mechanisms could be beneficial.
If a direct routing concept is used, as often occurring in infrastructure-less systems, i.e. MANETs or Pervasive/Ubiquitous Computing, local information about the neighborhood is available and firsthand communication between peers can be applied. However, the local information can get outdated. Thus, mechanisms to update this information are needed. Mobile P2P applications can benefit from *locality awareness*. In addition, a mismatch of the wireless network topology and the P2P overlay architecture should be avoided. Preferably, this can be achieved when combining mobile P2P self-organization with cross-layer optimization.

Common Wireless Constraints on P2P

Wireless links reveal significantly *less capacity* than wired connections. Hence, mobile P2P applications should minimize the amount of transmitted data, that is, signaling and pay load. Wireless links provide lossy communication. Their throughput varies strongly or shows high packet loss. Mobile P2P applications have to able to level these variations and should recover rapidly from data loss. Mobiles might notice a *sudden loss of radio connectivity*. Hence, mobile P2P systems have to implement *redundancy mechanisms*, e.g. fast reconnecting or retransmission mechanisms. In addition, mobile P2P services can level the *unavailability of user resources* if they take advantage of caching, prefetching, or replication mechanisms. The mobile units should limit their online time and data transmission since they typically have a limited energy reservoir. Mobile users may exhibit a *highly spontaneous* usage pattern due to the ubiquitous nature of mobile services. Combined with a sudden unavailability, this leads to a high *churn* of the mobile peers. The term *churn* denotes here the stochastic process of peer turnover as occurring when peers join or leave the system.

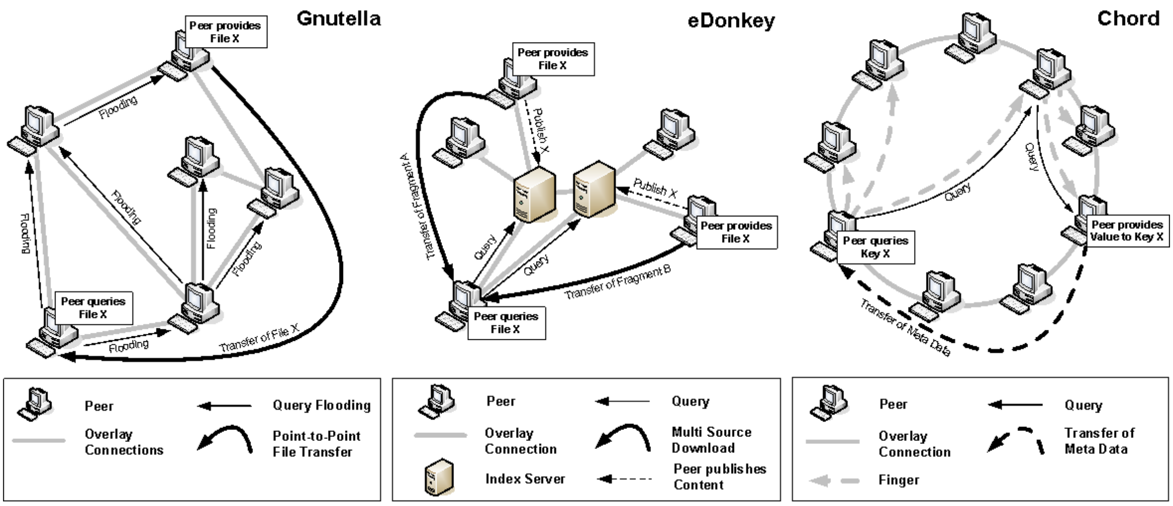
3 P2P Services

P2P comprises a large variety of mechanisms, architectures and applications. Colloquial, P2P is classified as "not client/server". In order to prepare the ground for a more accurate definition, three principal P2P architectures are outlined first, then P2P and mobile P2P are defined.

3.1 Popular Peer-to-Peer Applications

Gnutella

Gnutella [1] is an early P2P file-sharing overlay where users share arbitrary files without using central servers. It is setting up random overlay connections between peers for locating files. A flooding mechanism on the overlay connections is used to forward query messages to neighboring peers (cf. "flooding edges" in Figure 1a). Once a file is found, it is exchanged via a direct TCP connection (cf. "transfer edge" in Figure 1a). Gnutella is applying a direct routing approach from an application layer point of view. Due to the random structure of the overlay, Gnutella is classified as an *unstructured P2P architecture*.
The major advantages of Gnutella are the serverless operation and the simplicity of the flooding protocol, which permits a distributed file search. In Gnutella peers can join or leave the network arbitrarily. The main disadvantages are in turn the flooding concept and the randomness of the overlay, which both lead to high traffic load due to uncoordinated spawning of search requests (cf. Figure 1a). In addition, a limited search horizon lessens the probability of actually reaching a providing peer. Files stored on peers beyond a certain hop count will not be found.



(a) Gnutella (b) eDonkey (c) Chord

Figure 1: Fundamental P2P architectures

eDonkey

eDonkey is a popular, second generation P2P file sharing network [2]. It relies on specialized index servers for file location and the principle of *multiple source download (MSD)*. The MSD concept is enabled by a fragmentation of files to logical parts, e.g. blocks of fixed size. A requesting peer can download different blocks from multiple providing peers (cf. "transfer edges" in Figure 1b). In addition, the MSD concept enables peers to share fragments before completing a file. Since eDonkey peers can request and serve multiple blocks at the same time, a speedup of file transmission is achieved. A distributed scheduling concept is needed to coordinate the exchange of the blocks.
eDonkey peers publish and look up shared files using the index servers (cf. "publish edges" and "query edges" in Figure 1b). Hence, eDonkey deviates significantly from the pure P2P concept where all entities are similar. eDonkey is therefore denoted as a *hybrid P2P architecture*. The index servers handle all queries in order to relieve normal peers from query traffic. Hence, eDonkey applies a sort of indirect routing concept for queries.

Chord

Chord is a mechanism focusing solely on looking up data in a P2P overlay [3]. Key-value pairs are stored in a *Distributed Hash Table*. The Chord nodes form a ring structure and take responsibility for a part of the continuous range of hash key values. All query routing is based on the hash values (cf. "query edges" in Figure 1c). For efficiency reasons, so called *fingers* refer to distant hash values. These shortcuts limit the number of hops to find a key in $O(\log n)$, where n is the number of participating peers. If located, a pointer to the requested resource is returned by the responsible peer. In case of node failures, Chord reorganizes the responsibilities of the peers.

Chord is denoted as a *structured P2P architecture* due to the ordered, ring based topology of the overlay. The advantages of Chord are a fully distributed index, load balancing by fair distribution of the hash function value range, and the capability to complete localization of resources once being registered. The logarithmic routing cost ensures the high scalability. However, different capabilities of the peers are not considered. The efficiency of the Chord ring is reduced by frequent structural changes due to the complexity of the applied synchronization mechanism.

3.2 Definition of Peer-to-Peer

The concept of *P2P* can be defined as a highly distributed application architecture where equal entities, denoted as *peers*, voluntarily share resources via direct end-to-end exchanges on application layer. Typical resources are files or CPU cycles, however also metadata, e.g. locations of users or files, can be shared. A peer may be removed arbitrarily without resulting in any loss of service.
A *P2P service* is a loosely-coupled set of operations to provide a direct resource exchange. P2P services are typically focused on providing specific functions like distributed indices for locating resources or exchanging of files or resources.
The advantage of P2P services is the self-organizing, server-less, load-adaptive, and resilient operation of these services. A major characteristic of P2P is the forming of *overlays* on application level, representing logical relationships among peers. P2P overlays are categorized as *unstructured* in the case of arbitrary connectivity, e.g. Gnutella, or as *structured* if a predefined ordering scheme conducts the forming of the overlay, e.g. Chord. Its highly distributed nature distinguishes P2P from the centralized *client/server paradigm*.

Functions of Peer-to-Peer

In order to commonly use resources, P2P applications support two fundamental coordination functions: (i) *resource mediation*, and (ii) *resource access control* mechanisms.
Mediation mechanisms are functions to search and locate resources or entities and arbitrate *metadata*, which is data about data. Metadata is part of signalling, which is considered as overhead in P2P communication. Peers provide either mediation for own resources or more specialized peers bundle the information, thus making the search more effective. P2P mediation mechanisms vary from centralized index servers (cf. eDonkey) to decentralized mechanisms as flooding protocols (cf. Gnutella) or DHTs (cf. Chord). Central indices might easily be overloaded, flooding mechanisms do not scale in large environments, and DHTs suffer from high churn. Therefore, the selection of a mediation mechanism has to be based on a performance evaluation which considers these factors.
Resource control mechanisms are functions to permit, prioritize, and schedule the access to resources. They connect a data source (resource provider) with one or more data sinks (resource consumers). P2P resource control mechanisms have similarities to conventional *content distribution mechanisms* such as multicast, caching or prefetching. They differ from these concepts, however, by their decentralization, i.e. by the local implementation on peers which are typically edge nodes.

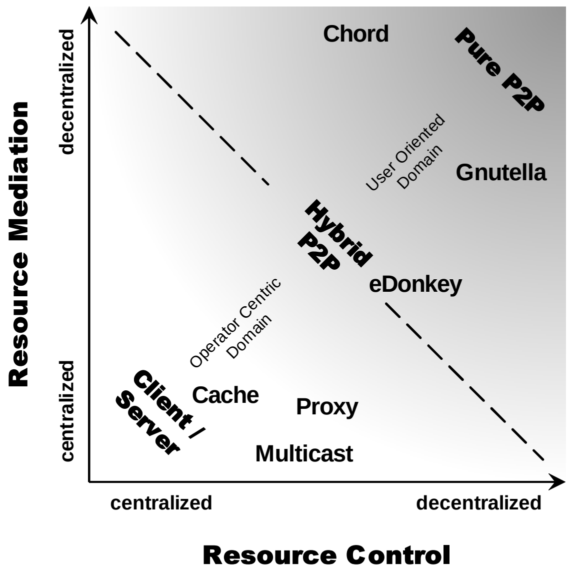


Figure 2: Cartography of P2P applications and content distribution architectures

The performance of resource access and delivery mechanisms depends on the resource availability, e.g. the number of peers providing a resource, the exchange strategy, i.e. which request is served first, and the transfer capability of peers, i.e. their access bandwidth.

Cartography

P2P architectures cover a broad range of structural choices. *Pure P2P* architectures, such as used in Gnutella, implement the two fundamental P2P control mechanisms in a fully decentralized manner, while *hybrid P2P* systems utilize central entities, e. g., the eDonkey index servers, that collect mediation data.
Figure 2 provides a two-dimensional cartography for comparing P2P architectures with other well-established information dissemination mechanisms. The basic P2P control functions (*resource mediation/resource access control*) form two orthogonal axes in Figure 2. The degree of distribution (*centralization/decentralization*) is used as the axes range. The cartography visualizes the architectural choices: the domain of *operator-centric* architectures, which aims at a strong centralization of control, and the domain of *user-centric* architectures, which typically endeavors a strongly decentralized nature of control. The cartography reveals the original focus of P2P on user-oriented services, whereas the most common information dissemination mechanisms use provider-operated infrastructure.

3.3 Mobile Peer-to-Peer

Mobile Peer-to-Peer services are P2P mechanisms and applications designed for mobile and wireless environments and address the special requirements in those settings, cf. Section 2.2. In particular, mobile P2P services support peer mobility by mobility management mechanisms

located on application layer. Depending on the application, mobile P2P services provide transport network level functions or application layer services.
The selection of appropriate mobile P2P mechanisms has to consider the mobility of the peers, the radio communication constraints, and the control needs such as the ownership of infrastructure (operator-centric systems) or edge services (user-centric systems). The above presented cartography of common P2P mechanisms gives a guideline for the architectural choices of mobile P2P. Furthermore a thorough performance evaluation is needed for fine tuning, e.g. for selecting an efficient resource access strategy for given mobility or a transmission capacity.

4 Overview on Mobile P2P Projects

Infrastructure-less

P2P techniques were first introduced in MANETs based on the suitability of direct routing for ubiquitous environments. A Gnutella like file sharing application for MANETs is proposed in [4]. The search path, established by broadcasting queries, is also used for data exchange. A further concept for file sharing in MANETs is suggested in [5]. The authors investigate how to embed the search for resources into the direct routing of MANETS, e.g. by broadcast-over-broadcast or by DHT-over-broadcast. A proactive approach for file exchange in infrastructure-less networks are epidemic data dissemination mechanisms [6, 7]. They make use of node mobility to spread information by direct, node-to-node communication. Spreading is performed for metadata or user files. This principle bypasses IP-based addressing schemes.
Typically, MANET nodes have only a local view of the network. Therefore, DHTs can be used in MANETs to establish a global perspective for mobile peers. DHT concepts for MANETs to improve routing are investigated in [8, 9, 10].

Middleware

The popular Java-based P2P framework *JXTA* is enhanced for mobile environments in a number of projects. The enhancements typically implement direct routing mechanisms for mediation and indirect routing schemes for specialized peers. A prominent project is JXME [11] which implements JXTA compatible functions on constrained mobile devices. The JMobiPeer project [12] avoids the indirect routing mechanisms of the JXME project. Proem [13] is a mobile P2P platform for collaborative applications in ad-hoc networks and uses broadcast and multicast mechanisms of the underlaying transport network.

Infrastructure-based

So far only a few mobile P2P concepts have been proposed for infrastructure-based wireless networks. Mostly, indirect routing mechanisms are used to cope with the node mobility and with constraints imposed by hierarchical architectures. Mobile proxy nodes are suggested in

[14]. The proxies perform P2P resource exchange by multicast on behalf of the mobiles, thus, relieving them from data swapping. A similar proxy concept using *surrogate hosts* is proposed in [15]. Direct routing in infrastructure-based networks can be facilitated by the application of DHTs. In [16] a *Hybrid Chord Protocol* is proposed which distinguishes between temporary nodes and static nodes. The key-value pairs are stored on static nodes, thus smoothing the performance reduction by churn which may result from mobility.

The analogy between P2P flooding mechanisms and MANET broadcast protocols make flooding-based P2P services highly interesting for ad-hoc networks, whereas central concepts, e.g. index server, might be more appropriate for infrastructure-based mobile networks due to the availability of dedicated equipment.

5 Mobile P2P File Sharing

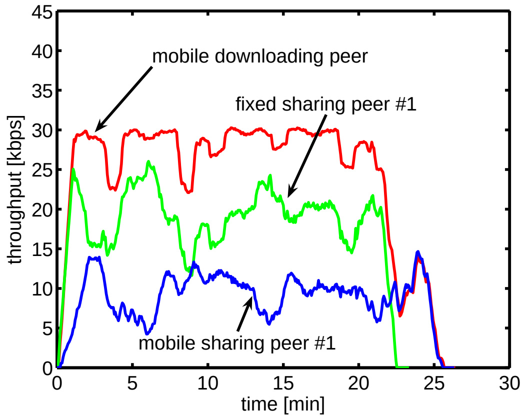
P2P file sharing might be an interesting service for mobile cellular operators: file swapping is highly popular among users and can obtain the high utilization of the networks. In particular, 3G/UMTS operators might offer a service which exploits the potential of the technology and which motivates the users to adopt it. Next, the expected performance and implied challenges of wireless file swapping is investigated. Then, an architecture for 3G/UMTS networks, which provides application layer support for high mobility, is derived and its performance is evaluated.

5.1 Challenges with Mobile File Sharing

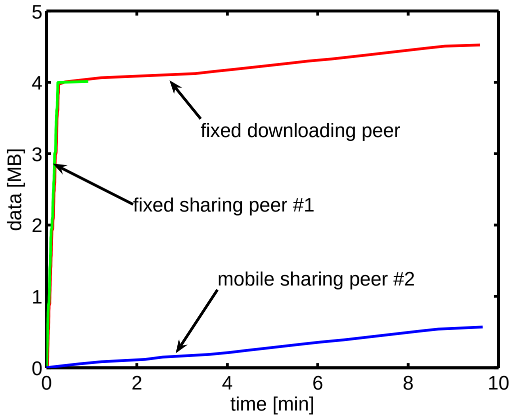
The expected download performance of mobile file sharing is investigated in a measurement study considering a simplified MSD scenario: a peer downloads a mp3 file of 4.8MBytes from two providing peers. The file is transferred with the mechanisms of the eDonkey system, cf. Section 3.1. Different access types for the peers have been considered, *fixed*: peer is located in the wired Internet and connect by Ethernet (10Mbps), *mobile*: peer is located in a public GPRS/UMTS network.

Figure 3(a) depicts the throughput in a GPRS system. It shows a fair bandwidth sharing: the providing mobile peer exploits its uplink and the providing fixed peer fills up the downlink of the downloading entity. In contrast to wireline networks, the downlink of the mobile peer determines the throughput in wireless systems. Figure 3(b) shows the case where the transmission of the last block of a file delays the download significantly. The downloading peer is located in the wired Internet but has to wait until the GPRS peer has sent all data.

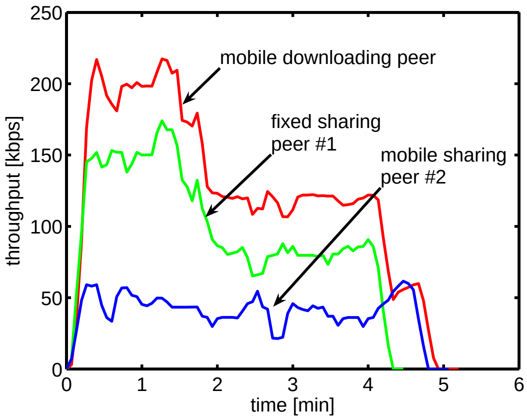
The measurements show that file sharing and multiple source download is feasible in cellular networks. The performance in GPRS systems is poor and a modification of the eDonkey scheduling strategy might be needed. However, the throughput in 3G/UMTS networks is sufficiently high, cf. Figure 3(c), and indicates that an efficient file sharing is possible in these systems.



(a) Throughput in GPRS



(b) Download delayed by mobile



(c) Throughput in UMTS

Figure 3: Multiple source download in a heterogeneous environment

5.2 Mobile P2P File Sharing Architecture for 3G/UMTS Networks

A mobile P2P file sharing architecture for 3G/UMTs networks can be derived from the cartography of P2P mechanisms by considering the functional constraints of these networks and its operational needs.

Design Principles

The continuing demand of users for a popular file sharing service often precludes the introduction of an entirely new application. The preference for maintaining control by an operator asks for a hybrid P2P architecture which uses special entities for resource mediation and which provides mechanisms for interacting with the data exchange. Thus, the cartography indicates that the hybrid eDonkey architecture constitutes a starting point for a solution. Moreover, the possibility to insert special entities and their indirect routing concepts might add further value for the user to the service, like improved mobility support on application

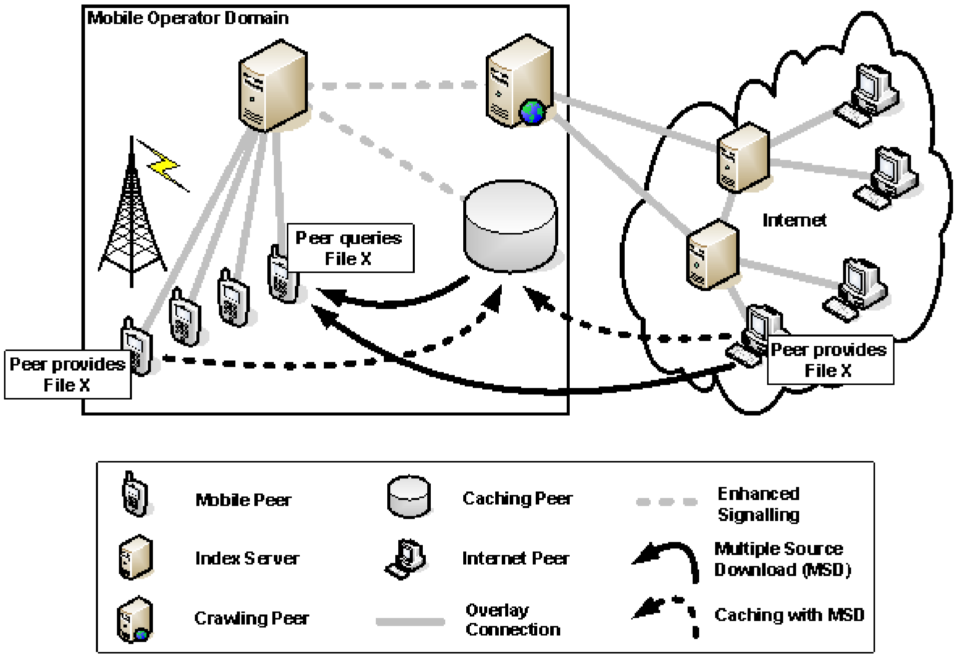
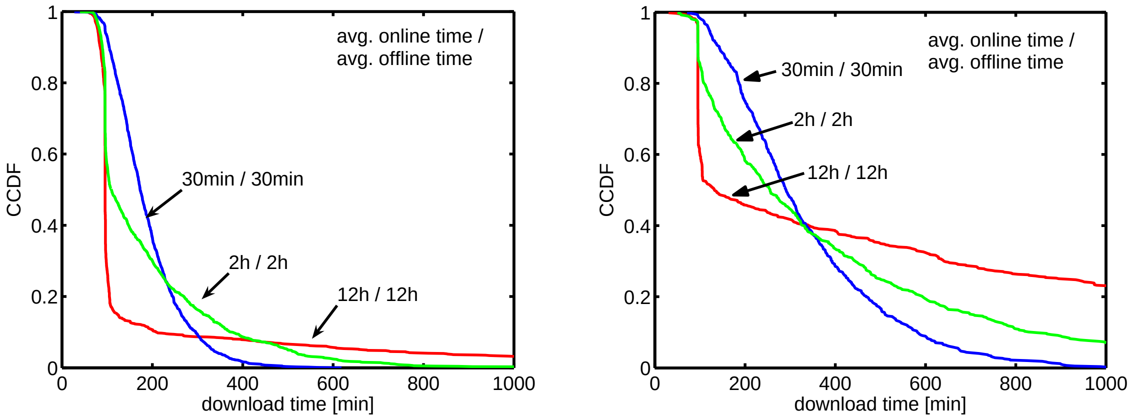


Figure 4: Mobile P2P file sharing architecture concept for infrastructure-based networks

level.

Architecture

The suggested architecture is depicted in Figure 4. The original eDonkey system is enhanced by three additional entities which are placed in the operator domain [17]: *a)* the mobile index server, *b)* the caching peer, and *c)* the crawling peer.
The *mobile P2P index server* is an enhanced eDonkey index server. It tracks frequently requested content, triggers the caching peer to fetch it, and forces the mobile peers to download files from the caching peer by returning it as the major source. It can also facilitate control on metadata, e.g it might deregister inappropriate contents. In addition, the mobile index server may implement mobility management on application level: it may inform other peers if a mobile entity goes online.
The *caching peer* is a modified eDonkey peer. It appears to be an ordinary peer, however, it distributes popular content. Since the caching peer is located in the wireline part it replaces mobile-to-mobile exchange by wireline-to-mobile communication, thus reducing the uplink data volume of mobile peers. Furthermore, the caching permits downloads even when original providing peers are off-line, thus improving the mobility of users. In addition, it avoids the multiple retrieval of the data across operator domains.
The *crawling peer (CP)* supports resource mediation, i.e. the locating of files. It searches sources of files on behalf of mobile peers, thus reducing the signalling traffic on the air interface. In addition, it can perform the task after the requesting peer goes offline. In this way, it increases also the mobility of peers.



(a) with caching peer (b) without caching peer

Figure 5: Download time performance under churn

5.3 Performance of the Mobile P2P File Sharing Architecture

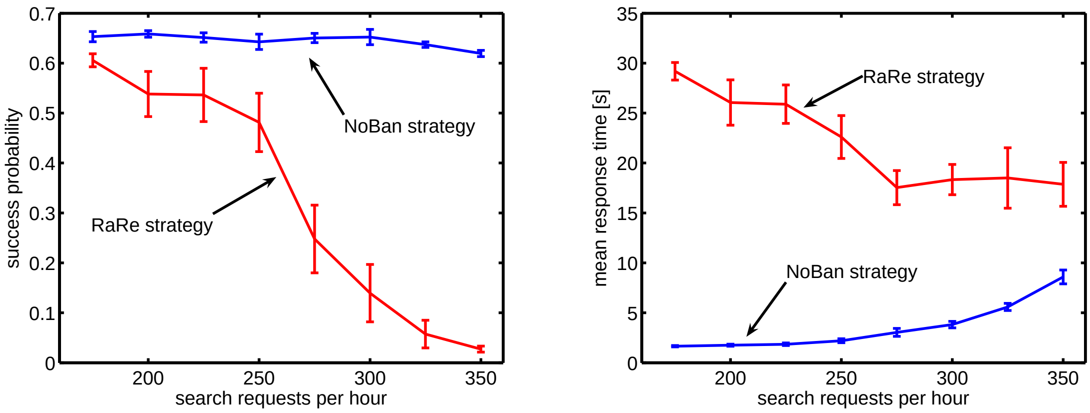
The performance of the proposed mobile P2P file sharing architecture is outlined by a simulation study considering churn and the impact of new elements on mobility support. A comprehensive investigation is available in [18, 19].

Resource Access Control: Caching Peer

The influence of the churn behavior on the download time is depicted in Figure 5 for downloading files of 5MBytes size with GPRS. Figure 5(a) shows the complementary cumulative distribution function (CCDF) of the download time for popular files, i.e. the files are provided by the caching peer, for details see [18]. The mobile peers with the smallest churn, i.e. average online/offline time of 12h, have the smallest download times. The more the churn increases, i.e. average online/offline time of 2h and 30min, the more the download time increases. Figure 5(b) illustrates the CCDF of the download time for unpopular files, i.e. no caching peer is used, under different churn. The download time is now significantly higher. This comparison shows that the additional infrastructure entity, the *caching peer*, reduces the impact of churn and makes the system more robust against the effects of mobility.

Resource Mediation: Crawling Peer

The crawling peer (CP) supports the resource mediation for a large number of peers. A high request rate of a peer, however, might overload every resource mediation mechanism. Therefore, the original eDonkey system has introduced as *scoring mechanism* that blocks peers which issue too many requests. Hence, an improved querying strategy for the crawling peer is needed which provides fast answers and which avoids blocking. In addition, since the CP is a centralized, typically non-scalable entity is has to be properly dimensioned.
Figure 6 compares two different CP strategies. With the *RaRe* strategy, the CP asks other index servers randomly. With the *NoBan* strategy, the CP remembers how often it has



(a) Success probability of search requests (b) Mean response time of successful requests

Figure 6: Influence of the request strategy on the performance of the crawling peer

queried other index servers and avoids asking them too often. Figure 6(a) shows that the RaRe strategy has a poor success probability for a high request rate whereas the NoBan strategy still return results with a high probability. Figure 6(b) reveals that suspending queries to certain entities in the NoBan strategy has no high impact on mean response time. The evaluation shows that a proper dimensioned CP is able to add its additional value to the mobile P2P architecture.

6 Conclusion

Mobile Peer-to-Peer services are P2P services designed for mobile and wireless networks. They address the environmental constraints of radio communication (restricted and highly variable throughput, sudden disconnectivity, location-dependency), and in particular, the mobility of peers. Mobile P2P services can provide mobility management mechanisms on application level.

The selection of an appropriate mobility management for mobile P2P services depends essentially on the wireless network architecture (infrastructure-based/infrastructure-less), the applied routing mechanisms and the type of supported mobility. The parallels of architecture, direct routing schemes, and mobility make unstructured P2P systems interesting for ad-hoc networks. Indirect routing can take advantage of the given infrastructure and support high mobility. Therefore, mobile P2P systems which are enhanced by centralized entities, such as caches or index servers, are more appropriate for infrastructure-based mobile networks. Such an architecture enables the operator to *a)* participate in service creation and service control, *b)* to offer value-added services, while *c)* maintaining the characteristic of direct and efficient interaction between highly mobile users.

However, research on mobile P2P services and their mobility management mechanisms is still at an early stage. A more systematic investigation of these applications and mechanisms is needed, e.g. what scalability can be obtained for the different mechanisms or how should they be changed in order to yield mobile P2P services with combined high performance and high reliability? The answers to these questions will facilitate truly ubiquitous mobile services.

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