Potentials and Challenges of Peer-to-Peer Based Content Distribution

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Abstract

Multimedia content currently accounts for over three quarters of all Internet traffic. This increase in traffic volume and content availability derives from a paradigm shift from the traditional text and picture based Web, to more resource demanding audio and video content. A controversial driver for this development is content distribution systems based on peer-to-peer overlay networks. Flooding the Internet with often illegal content, these networks now pose challenges to all actors in the value chain. However, if viewed as surmountable challenges in an evolutionary path, peer-to-peer technology has the potential of increasing efficiency in content distribution and unleashing resources to form scalable and resilient overlay networks of unprecedented dimensions.

In this paper we examine the potentials and challenges of peer-to-peer technology in content distribution, and analyse how, and in which circumstances, peer-to-peer technology can be used to increase the efficiency of multimedia services.

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The paper provides an up-to-date overview of the development of peer-to-peer networks as well as describing the economics laws governing their use. To conclude the study, the paper analyses Skype, a well known telecommunications service utilising the peer-to-peer technology, as well as demonstrating the benefits of peer-to-peer based content distribution using empirical data from the Danish Broadcasting Corporation.

Keywords: Content Distribution, Peer-to-Peer, Multimedia

1. Introduction

The Internet has seen a proliferation of multimedia content in the past decade. Recent studies indicate a drastic shift of Internet traffic away from text based HTML pages and images towards more resource demanding multimedia content (Saroiu et al., 2002; Sripanidkulchai et al., 2004a, 2004b). Rapid Internet growth and digitalisation of audio / video (AV) content has enabled a wide range of multimedia applications for residential users (Odlyzko, 2003). Consumption and demand for content has been reinforced by the availability of broadband connections capable of delivering high quality continuous media. Content providers and market supply has traditionally been lagging market demand, mostly due to content owners' fear of copyright violations. In the meantime users have built up communities of their own based on the peer-to-peer (P2P) technology. These networks take advantage of the immense number of often underutilised end systems by storing increasing amount of content locally at peers. This shift from expensive centralised hardware, operated and controlled by operators and service providers, to perceivably free decentralised user driven systems has resulted in network communities of unprecedented scales.

After a growth period, dominated by the use of file-sharing applications and motivated to a large degree by access to copyright protected material, peer-to-peer networks now stand at the brim of a new evolution; adaptation into a wide spectrum of mainstream applications. In this role peer-to-peer networks must compete on even grounds with other methods of content distribution. In this new role, viability and proliferation of peer-to-peer networks is measured through technological and economical efficiency and competitiveness. Today, the potentials of peer-to-peer networks are reflected through hugely successful file sharing and VoIP applications, which through active research and development in the past few years can offer stability, redundancy, and scalability at a fraction of the cost of traditional server based services. Despite success in some areas, the Achilles heel of peer-to-peer technology has been its inability to represent a complete revenue model accounting for all players involved in value the chain of content distribution. This is largely due to legal uncertainty surrounding the use and conflict of interests where e.g. users regard traffic and content as free commodities while internet service providers bear increasing cost of transmission[2] and the music industry reports decreasing record sales due to file-sharing[3]. Estimating the economic efficiency and competitiveness of P2P aided applications in *legal* content distribution will be the focus of the rest of this paper.

1.1. Motivation

This paper is motivated by the immense potentials of peer-to-peer networks for content distribution and the somewhat errant path of their development. This becomes evident through the contrast of the enormous success of peer-to-peer based telecommunications service provider Skype, compared to the rampant increase in peer-to-peer aimed legislation (PDEA Act, 2004; PIRATE Act, 2004) and prosecutions[4] and the uncertain future of classical file sharing habits[5].

1.2. Contribution and Structure of the Paper

In this paper we advocate the use of economic analysis to understand the applicability and role of the peer-to-peer paradigm in future multimedia applications. In Section 2, we start by giving a chronological overview of the development of peer-to-peer networks, revealing that the development path of peer-to-peer networks can be divided into four distinct eras. In Section 3 we go on to analyse the economic laws governing the use of peer-to-peer technology and develop an economic framework to study the use and sustainability of peer-to-peer networks in competition with alternative 'traditional services'[6]. The analysis is based on calculating and comparing the utility that users and service providers get from using and offering the two types of services. The rationale behind this study is based on the hypothe-

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[2] Parker (2004) estimates a €100M per annum cost of transit for ISPs in Western Europe alone.

[3] This claim is subject to debate as e.g. Oberholzer and Strumpf (2004) show that the claim of file-sharing being the primary reason for the recent decline in musical sales is unsubstantiated.

[4] For an excellent introduction and overview of the legal and policy challenges of peer-to-peer technology visit Berkeley's (2005) course page.

[5] While some sources indicate a decrease in peer-to-peer traffic, studies such as a nationwide phone survey reported by Pew Internet (2004) following a RIAA action may be subject to "hiding" as also observed for the traffic by Karagiannis (2004).

[6] In the context of this paper we do not define the term "traditional services" but use it to indicate competing network architectures such as client / server.

sis of the authors from (Sigurdsson, 2005) that '*Peer-to-peer technology will only prevail if it offers higher utility to both peers and service providers than competing transmission technologies, given the same quality level'*. In Section 4 we apply the developed framework to analyse the business and revenue models for peer-to-peer services. This part of the study draws on the conclusions from Eurescom research project P-1553 – 'The impact of peer-to-peer networking on network operators and Internet Service Providers' (Eurescom, 2005) as well as a framework for peer-to-peer revenue models, introduced by Hummel et al. (2005). In Section 5 we use SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis[7] to reflect the potentials and challenges of peer-to-peer based content distribution based on the frameworks and methods of analysis developed in the previous sections. We use the case of Skype, a well know telecommunications service provider, in Section 6 to demonstrate efficient use of peer-to-peer technology. In Section 7, we demonstrate the potential benefits of peer-to-peer technology through "Server Initiated Peer-to-Peer" developed by the authors in (Sigurdsson, 2005), applying it to empirical data from the Danish National Broadcaster. Finally in Section 8 we finish the paper with conclusions.

2. History

This section presents a panoramic look at peer-to-peer networks and their evolution in recent years, from the file-sharing explosion some five years ago to the emergence of innovative architectures and user habits more recently observed. We describe the development in a chronological order, dividing the development path into four distinct eras. This classification is subjective but based on developments of network architectures, new applications and usage scenarios over time. A summary is provided in Table 1.

Table 1, Development of peer-to-peer applications

[7] For an overview and guidance in applying SWOT analysis see Sørensen and Vidal (1999)

	1st Era	2nd Era	3rd Era	4th Era
Period	1999 – 2001	2000 – 2002	2002 – 2004	Reccent trends
Architecture	Centralised search, P2P data transfers	Decentralised, partly hierarchical	Hybrid	Hybrid
Applications	Mainly file-sharing	Mainly file-sharing	File-sharing, Software distribution, Instant messaging (IM)	File-sharing, IM, Streaming, VoIP, Gaming, Cooperative working
New Functions	Sharing of data and resources	Distributed search and data transfer	Scalable, resilient structure, parallel multi source up- and download	Integrating P2P functions in special purpose solutions
Popular networks	Napster	Gnutella, Freenet	FastTrack, eDonkey, BitTorrent, MSN Messanger	Skype, PodCasting, networks for smaller communities

2.1. First Era – The Rise of Peer-to-Peer Networks

Digitalisation of audio and video content and universal coding standards, such as MPEG-1 and MPEG-2, gave consumers of the late 1990s the possibility of reproducing and sharing their content over the Internet. Without contact with the original content provider, users formed communities based on the concept of sharing their own content and in return getting access to the content of everybody else. Although violating the intellectual property rights of the producer, this provided a file sharing platform for millions of users that only had to pay for transmission (i.e. their connection fee to the Internet). This form of content distribution was further reinforced with the introduction of special Peer-to-Peer (P2P) networks, in particular Napster.

Napster was created in 1999 and was the first widely-used peer-to-peer music sharing service, making a major impact on how people, especially youth, used the Internet. Napster used central servers to maintain lists of connected systems and the files they provided, while the actual transactions were conducted directly between machines. This architecture achieves efficient searching and high degree of control of the network to its owners. Its main disadvantages are vulnerability to server congestion and failure, and last but not least, the high degree of exposure to legal responsibility.

As the popularity of Napster grew, the worries of content owners and producers grew. The fact that they were forced out of the value chain of millions of consumers caused them to press for legal actions against P2P networks. This resulted in a series of lawsuits, which eventually lead to Napster closing in 2001, after reaching a peak of 25 million users worldwide in February 2001. Although successful in closing Napster, these actions spurred development of a new generation of peer-to-peer networks.

2.2. Second Era – Decentralised Peer-to-Peer Networks

Following the popularity and eventual closure of Napster, several new applications emerged. Most of these applications aimed at remedying the centralised venerability of Napster by decentralising the control functions, thus making it difficult for opponents to elect a preferential target for lawsuit.

The most popular second era applications were Gnutella and KaZaa (uses FastTrack). Gnutella was created as a network without centralised control, working in a pure P2P fashion not only concerning the actual exchanges of content but also with respect to control and signalling procedures such as login and search operations. In the Gnutella network a new node signals its presence to another online node in order to initiate a session. The peer node will respond and in turn propagate this new presence to other nodes in a chained fashion. Node addresses for login may be drawn from known lists or chosen from known friends. Searches are propagated in a similar way until a positive result is found.

The greatest advantage of decentralised architectures is their resilience to external control, due to its entirely distributed architecture. This very characteristic, however, also constitutes their main problem. This is due to the fact that control messages grow exponentially with the number of nodes, causing these networks to scale poorly and show some tendency to behave as several disjoint, smaller networks. Gnutella later evolved to offer better response by adopting a so-called hybrid architecture, which tries to offer the best of both worlds (Eurescom, 2005).

2.3. Third Era – Efficient File-Sharing

This era is characterised by hybrid architectures, combining the features of both centralised and decentralised systems. This was accomplished through the introduction of specialised nodes in the network, sometimes called supernodes that work as concentrators for signalling, indexing and search functions. This allows a better scaling of the network by reducing the number of nodes involved in message handling and routing, and the traffic volume between them. The role of supernodes is to allow faster processing of queries making the performance of a hybrid network comparable to a centralised network model. Supernodes may be dynamic in time and location, adjusting to network topology and available computing and communications resources. FastTrack, eDonkey and BitTorrent are perhaps the most famous of the 3rd era networks. The new version of Gnutella, known as Gnutella II can also be considered 3rd generation.

FastTrack added a number of enhancements to P2P networks, most importantly the capability to download from multiple sources in parallel. Multi source downloads of data blocks segmented from a large file improves the throughput of the data exchange, since small data flows between peers can be set up independently of the access speed at each peer and connections to multiple sources make a download less dependent on the availability of each source, which is affected by users going offline.

FastTrack also introduced supernodes as a level of a hierarchical structure in contrast to a pure P2P principle. Nodes can become supernodes if they satisfy certain performance and communications criteria. These improvements contributed to better search and download performance as well as enhanced network scalability.

The eDonkey network is also considered as a hybrid architecture although it has some differences in the use of decentralised index servers, which are only dynamic in a longer term; eDonkey is designed with the intent of sharing large files in mind, typically movies or software. To optimise this, it divides large files into smaller segments or chunks using universal rules. Segments are identified and validated by hashing methods, thus avoiding corruption and attack. Simultaneous download from multiple sources and simultaneous upload of still incomplete files are both possible. Anyone is free to set up an index server using two well-known server applications (Lugdunum and the open-source MLDonkey). During a session, only one index server is consulted at a time and no information is exchanged between servers. Although servers may change when a new one is set-up or deactivated, they stay relatively stable over time. For these reasons, eDonkey is sometimes called a semi-centralised architecture.

BitTorrent is a newer protocol which improved some known functions of eDonkey for efficient distribution of large data volumes. It uses a similar strategy for the exchange of large files by segmenting them. Fragment size is variable in order to adapt to the total file size where blocks of about 12kByte are usually exchanged between two peers in a TCP connection. Controlling nodes are called trackers and peers are called seeds if they possess a complete version of the file or leechers if they are still at completing their download. A tracker is present for each file, which introduces a network structure according to the content.

Avalanche, is an emerging new file-sharing protocol, still in the making at Microsoft Research. Avalanche uses similar methods to BitTorrent but adds network coding (Ahlswede et al., 2000; Chou, 2004a). Instead of distributing the blocks of the file, peers produce linear combinations of the blocks they already hold. Such combinations are distributed together with a tag that describes the parameters in the combination. Any peer can generate new unique combinations from the combinations it already has. When a peer has enough independent combinations, it can decode and build the original file (Gkantsidis, 2005).

2.4. Fourth Era – Beyond File Sharing Applications

Today, there is an increasing tendency to use peer-to-peer applications for real time communications and for streaming video (Chou, 2003b; Li, 2004). In less than two years after its foundation, the Skype peer-to-peer solution for voice over IP (VoIP) reached global market leadership in VoIP. Assuming that the future will be dominated by legal multimedia services that will require an infrastructure for the delivery and consumption of multimedia content, the role of P2P will change. P2P will move from being a separate marketplace on its own into merely being an alternative technology for content delivery. It then has to compete on even grounds with other methods of content delivery. Peer-to-Peer technology will then not only be used for file sharing but will seamlessly integrate into advanced multimedia services. Among the most likely application types are:

- Conversational services
- Collaborative tools
- Multi user games and e-learning
- Manifold types of content distribution

Content distribution networks (CDNs) were introduced to improve the performance of static or transaction-based Web content[8]. In recent time streaming media, radio, Internet TV etc. have become an increasing portion of their content. Starting from a client-server based architecture, popular servers are supported by surrogate or cache servers. In this way an overlay network is established often based on the infrastructure of a content distribution network to avoid bottlenecks at servers and to reduce the access time to content by shortening transmission paths to clients (Popesccu et al., 2006). Using a rigid infrastructure enables better utilisation of resources and full control over content and its distribution.

One of the main issues of CDNs is where to place the caches or surrogate servers. This is a trade-off between the costs of resources (hardware, provisioning, and access bandwidth) and transmission distance to the con-

[8] Akamai is probably one of the most widely knows CDN. Core offering is distribution services (both http content and streaming media), but recently other services have been added including network monitoring and geographic targeting. For further information see http://www.akamai.com/

sumer. Main challenges lie in an efficient content management and routing of content to satisfy the user demands as well as measurement to confirm a sufficient level of the perceived QoS.

Content distribution via peer-to-peer networks goes a step beyond towards a completely distributed structure involving the resources of the peers interested in the content. P2P content distribution allows for more flexibility in the overlay network, which may be structured according to different content e.g. by trackers for each item in the BitTorrent network or according to other criteria. The size of the overlay can automatically adjusts to the population of peers and thus user demand with a replication strategy for the data being set up by the P2P protocol.

On the other hand, there are still open issues on control of usage and delivery which are of great concern to content owners and providers. In addition, no guarantee for perceived QoS can be assured in current global P2P overlays, where each peer may enter or leave the network at any time. While ongoing research is addressing QoS in P2P networks (Heckmann, 2006), incentives for peer participation are essential to ensure sufficiency of resources. This can be accomplished e.g. through admission control or by inducing peers to contribute resources through some form of incentives.

One of the key issues that can facilitate evolution of future applications is the adoption of Digital Rights Management (or at least avoidance of conflicts with IPR). In contrast to earlier file sharing applications that violate Intellectual Property Rights (IPR) of audio, video, software etc., future applications will take advantage of the technical benefits of peer-to-peer networks, without exploiting intellectual property rights. Nevertheless, resource and file sharing will prevail, since the volume of interesting unlicensed multimedia content provided by single users and communities on the Internet is increasing.

3. Economic laws governing peer-to-peer networks

As the use of peer-to-peer networks has become more widespread the question of why and when they should be used becomes more important. In the following section we will apply methods of economic theory to investigate the use and sustainability of peer-to-peer networks in competition with alternative “traditional services”. The analysis is based on calculating and comparing the utility that users and service providers get from using and offering the two types of services. In the next section we will try to apply this framework of analysis to the future role of peer-to-peer networks.

3.1. Competitiveness of peer-to-peer technology

Effectiveness of data transmission services has typically been measured in how well they utilise constrained capacity in congestion prone networks (Hefeeda, 2004). The design and pricing of data transmission services has therefore typically focused on designing schemes that optimally allocate capacity. However, development and increased capacity in both backbone and access networks in recent years, has introduced resource abundance in many domains of the Internet. Resource abundance, built-in TCP fairness, and technical complexity of measuring and controlling Quality of Service (QoS) parameters have led to relatively simple pricing schemes in residential access networks.

Pricing of data transmission in residential broadband access networks has mainly taken two forms: fixed prices for access with differentiation according to access speed, or volume prices for measured extra-domain traffic. Both these pricing schemes increase the attractiveness of peer-to-peer technology for users since content can either be transmitted over underutilised fixed priced links or non-priced inter-domain links. With a growing and unsaturated market for residential broadband connections and ample excess resources, most ISPs have focused on extending their customer base, rather than worrying about allocating capacity optimally. With documented levels of peer-to-peer traffic around two thirds of all backbone traffic, ISPs are experiencing increasing transmission cost from peer-to-peer traffic.

3.2. Applicability of peer-to-peer applications

Nowadays, peer-to-peer networks are being incorporated into an increasingly wider spectrum of applications. However, there are sceptics that point out that the underpinning force of peer-to-peer applications is massive exploitation of intellectual rights. In earlier work Sigurdsson (2005) explored the use of economic methods to understand the necessary conditions in which commercial peer-to-peer network can prevail. The hypothesis was that "*Peer-to-peer technology will only prevail if it offers higher utility to both peers and service providers than competing transmission technologies, given the same quality level*". The rationale here is that consumers would not use a peer-to-peer aided application if it offered lower quality or incurred higher cost than competing applications. The service provider on the other hand would not use peer-to-peer technology unless it was less expensive to deploy and maintain. In both scenarios the question of how to persuade peers to contribute resources arises.

3.3. Economic analysis

The economic analysis is based on the principle that interaction between peers and service providers is governed by the utility that both obtain from participation. We assume that digital content can be consumed in discrete amounts, where quality level is linear and directly proportional to the consumption rate. The utility that a peer p_i gets from the consumption of Digital Item j at quality r, is represented by $u_i(r_j)$. The price that peer p_i pays for r_j is furthermore $v_i(r_j)$. To control the reward that the peer p_i gets from sharing his resources, we introduce the inducement factor α. The amount of resources S_i that peer p_i offers to the network weighted by the inducement factor α represents a monetary reward αS_i. When users contribute resources, they can not use the same resources during that time. Assuming that contributing resources to the peer-to-peer networks incurs negative utility for peers, we introduce an opportunity cost factor β. We assume that this cost factor is an unknown positive constant that represent peers utility of the resources reserved for sharing, and that the total lost utility due to the opportunity cost is βS_i. Table 2 lists all definitions of the symbols used in this chapter.

3.4. Maximising peer utility

We assume that peers are rational, autonomous, self-interested economic agents, whose utility stems from consumption and transaction of digital items. If the service provider sets the price $v_i^{P2P}(r_j)$ equal to the price of the same Digital Item delivered through traditional service $v_i^{trad}(r_j)$, and decides upon an inducement factor α, each peer is faced with the problem of optimising his own utility through Equation 1.

Equation 1.

$$U_{i,j}^{\mathrm{P2P}} = \max\left[u_i(r_j) - v_i(r_j) + \alpha S_j - \beta S_j\right]$$

From Equation 1, we deduce the peer utility for traditional services by setting $\alpha = \beta = 0$.

Equation 2.

$$U_{i,j}^{\mathrm{tra}} = \max\left[u_i(r_j) - v_i^{tra}(r_j)\right]$$

Given that the quality level is the same in both systems and that $v_i^{\mathrm{P2P}} = v_i^{\mathrm{trad}}$, comparison shows that the total utility of P2P aided services is only higher than that of traditional services *if the reward gained from sharing is higher than the opportunity cost of sharing* as shown in Equation 3.

Equation 3.

$$\alpha \geq \beta$$

If this does not hold, peers gain less utility from participating in P2P aided services than from using traditional services and will therefore choose traditional streaming. A special case of Equation 1 arises when we look at the current peer-to-peer based file sharing networks where no fee is paid for content and no reward is given, i.e. $v_j(r_j) = \alpha = 0$. The utility then becomes positive as long Equation 4 holds.

Equation 4.

$$u_i(r_j) - \beta S_j \geq 0$$

Equation 4 therefore demonstrates that the popularity of current P2P networks remains as long as the total utility is positive while consumption utility is higher than the opportunity cost of sharing. Due to the great number of underutilised end systems with flat rate Internet connections the opportunity cost is very low, and thus many will participate if the content available is of interest to them. When the opportunity cost increases, e.g. through the fear of legal prosecution or introduction of content fees, participation becomes less attractive.

Table 2, Symbols used in the economic analysis

Symbol	Description
α	Inducement factor
β	Opportunity cost factor
γ	Depreciation factor
p_i	Peer i of N peers participating in the system
r_j	Rate at which digital item j is consumed
i	Index for peer i
j	Index for digital item j
$u_i(r_j)$	Consumption utility that peer p_i gets from r_j
$v_i(r_j)$	Price that peer p_i pays for consumption of r_j
$U_{i,j}=$	Sum of all utilities for peer i due to digital item j
C	Total cost
q^{lic}	Licence fee
L	Total number of digital items served
$I^{\text{trad}}(L)$	Investment required in a traditional system to serve L
$O^{\text{trad}}(L)$	Operational cost for a system serving L
I^{P2P}	Investment required in a P2P system
O^{P2P}	Operational cost in a P2P system

3.5. Maximising service provider's profit

We assume that service providers are rational, autonomous profit-maximising economic agents. We also assume that there is equilibrium and perfect competition in the market for traditional streaming services and that numerous small service providers are price takers, all with very similar operational cost. The general structure of total cost (C) of both P2P aided services and traditional services is a function of the number of digital items served (L) by the systems as described in Equation 5 and 6[9].

Equation 5.

$$C^{trad}(L) = q^{lic}(L) + O^{trad}(L) + \gamma \cdot I^{trad}(L)$$

Equation 6.

$$C^{P2P}(L) = q^{lic}(L) + O^{P2P}(L) + \alpha \cdot L \cdot R + \gamma \cdot I^{P2P}$$

In the equations, $q^{lic}(L)$ represents licence fee for content L, $O(L)$ is the operational cost which is considered to be the same in both systems, i.e. $O^{trad}(L)=O^{P2P}(L)$, γ is the depreciation factor which is proportional to the decrease in the monetary value of the investment I (or required rate of return of investment) in the system. For the P2P system the investment cost is fixed[10], but for the traditional system it is a step function, representing required steps of investment to support customer base demand of L. When capacity of hardware is exceeded, a new installation with an increased capacity is required. The term $\alpha \cdot L \cdot R$ represents total monetary reward paid to peers for participation.

We assume that traditional service providers can always meet increased demand by investing in additional resources and that P2P service providers can increase customer base and therefore supply by adjusting their α. We ignore the lag in supply and demand caused by purchase and installation of additional resources. A service provider looking for the least expensive solution when choosing among the two will base his selection upon the outcome of Equation 7 since the two options will get the same income and since the licence fee and operational cost are the same.

Equation 7.

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[9] For simplicity we disregard differences in licence fees and cost between digital items

[10] We use the conceptual model developed by (Sigurdsson, 2005) of a seeding server that is used to initiate content dissemination into the network, and not serve clients directly.

$$\text{Decision} = \begin{cases} \text{Traditional,} & \text{if } \gamma I^{\text{trad}}(L) \le \alpha L R + \gamma I^{\text{P2P}}, \\ \text{P2P} & \text{else.} \end{cases}$$

Assuming that investment cost is proportional to the number of clients served, we have $I^{P2P} << I^{trad}(L)$ and thus a P2P operator will have the cost savings of $\gamma \cdot I^{trad}(L) - \gamma \cdot I^{P2P} - \alpha \cdot L \cdot R$. To be profitable, the P2P provider has to adjust α within the limits of Equation 8. The P2P service provider can then adjust the price and the inducement factor to obtain the operative equilibrium he chooses. For simplicity, we assume that service providers only adjust the inducement factor, but generally they could attract more customers from traditional services by lowering the price, and increase capacity by raising α:

Equation 8.

$$0 \le \alpha \le \frac{\gamma I^{\text{trad}}(L) - \gamma I^{\text{P2P}}}{L R}.$$

Equations 7 and 8, show that P2P aided services will not prevail in the market, unless the total cost of operating such a system is lower than the cost of operating a corresponding system with traditional streaming.

4. Business and revenue models for peer-to-peer services

The main challenge in designing feasible business models for peer-to-peer networks are generally related to establishing a revenue framework which accounts for all participants in the value chain. Eurescom (2005) provides a detailed overview of the structure, interconnection, and revenue models of P2P. The classifications of participants in P2P business models is based on the revenue-model framework proposed by Hummel (2005):

- Content provider
- Legal owner of content
- Receiving partner
- Mediating service
- Network and Internet service providers

Using this framework, one can argue that Napster’s business case did bridge a certain gap in the market by providing almost unlimited free access to digital content to users, while generating revenues by advertisements in an indirect revenue model. On the other hand, legal implications followed since the underlying revenue model did not account for all parties involved in the value-chain.

From the Napster case, two fundamental and directly connected difficulties with finding feasible peer-to-peer business models become evident:

- difficulties in tracking the type and origin of content being transferred in (decentralised) peer-to-peer networks
- difficulties in charging for provided content, since the receiving partner and type/origin of content are unknown and not coordinated in a centralised manner.

In principle, to account for these problems, the following two criteria need to be considered

- incorporate centralised facilities, which assist the peer-to-peer applications in keeping track of usage and directing revenues to appropriate business model partners
- the "providing partner" and "the legal-owner of content" have to be the same or closely related business partners.

Similar services like Napster, but based on different charging approaches, have been successfully implemented and exhibit how feasibility of peer-to-peer services and applications depend on the underlying revenue-business-model. For example, in the US, paid music downloads are on a rapid rise, making it evident that users are willing to contribute to the revenue flow and. As a result a variety of peer-to-peer based business models may be conceivable (Oberholzer, 2004).

Peer-to-peer based collaborative tools are a class of services satisfying the criteria above by offering services to share digital content with the aim of supporting groups of individuals, departments and companies, when working together in joint-effort projects. Such services can offer email, chat, bulletin boards, calendar and scheduling, file-sharing and search-engine services, just to mention a few possible utilities. In this scheme the workgroup is typically organised by a centralised utility offering a simple means to allocate rights to users for accessing, distributing or working on digital content provided by the network. In this case, the legal aspect of content loses its importance, since all participants are well defined and authenticated members of the workgroup, participating in a project with a predefined common objective in mind. Based on these prerequisites it becomes easy to define feasible business models, which can be based on selling Groupware applications or on hosting applications for bringing collaborative services to users.

Conversional peer-to-peer services can exploit the property of the "legal owner" of content, e.g. a message or a voice stream, to coincide with the "providing participant" in the business model. This feature relaxes the legal-prerequisites required to defined a feasible revenue model and has paved the way for a wide spectrum of communication oriented services. For generating the revenue flow, there are in principle two different possibilities for implementing the charging mechanism,

- either by charging for the use of software applications which give access to peer-to-peer networking (application based approach)

- or to offer the software for free and charge for the services used by participants (service based approach).

The application based approach is straightforward, while in peer-to-peer networking the measuring and accounting for usage is complex and difficult to handle. This could be one of the major reasons why Microsoft decided to build their MSN messenger on a server/client structure in contrast to unsuccessful IM competitors using applications based access, such as AIM and Yahoo! (Eurescom, 2005).

Despite development of new peer-to-peer based business models, interest in participation in peer-to-peer based networks that exploit IPR does not necessarily disappear. However, the increasing amount of digital content, and the emergence of resource demanding technologies such as HDTV indicate that the importance of efficient content delivery will increase. It can therefore be concluded that there currently exists a prospective market for peer-to-peer based content distribution and that this market will continue to grow in the future.

5. SWOT analysis of peer-to-peer technology

As discussed in Section II, the history of peer-to-peer networks can be described as a technology driven by innovation and continuous development while characterised by conflicts of interests. In this section we give an overview on the strengths, weaknesses, opportunities, and threats which shape the peer-to-peer business and technological environment.

5.1. Strengths

- Abundance of underutilised end-equipment and broadband transmission capabilities.
- Efficient distribution of data over the Internet with built in scalability.

- Facilitates global services based on decentralised and adaptive infrastructure.
- Global decentralised and adaptive infrastructure with built in redundancy.
- Strong support from independent development community.

5.2. Weaknesses

- Difficulties in supervising and monitoring content in peer-to-peer networks cause problems when designing and implementing security and authentication mechanisms.
- Lacking a dedicated central server with well defined properties, it becomes difficult to guarantee QoS and heterogeneity in data transfer characteristics.
- The missing centralised utility for monitoring and coordinating data and revenue flows make the design and implementation of new business cases difficult.
- Flat-rate charging principles are rapidly growing in popularity. Combined with the massive peer-to-peer data transfer capabilities these can have a significant impact on current network operator and ISP business models.

5.3. Opportunities

- Bypassing the necessity of centralised servers and network infrastructures significantly reduces the related maintenance and investment costs.
- The strong scalability features of peer-to-peer networks offer a platform for a wide spectrum of prospective services to be developed and deployed in the near future.
- New approaches to service design and provision fosters development and innovation and drives broadband adoption.
- Open sources software and inexpensive resources reduces barrier to entry both in service and infrastructure

5.4. Threats

- The decentralised nature of peer-to-peer traffic limits possible supervision and control of illegal and/or manipulated content, making peer-to-peer networks subject to further legal disputes or legislative actions.

- Peer-to-peer networks are subject to attacks induced by malicious peers, e.g. deterioration of network performance, spreading of tempered content, spam or spying of content.
- Peer-to-peer traffic is observed to consist of rather slow data streams (Saroiu, 2002; Sripanidkulchai et al., 2004a, 2004b), primarily because of asymmetric access network with low up-stream rates
- Peer connectivity and transmission properties may not be suited for all types of future services.
- Peer-to-peer server structures impose uncertainties in continuity and quality in data transfer properties, which can impact issues like stability, redundancy and QoS.

Table 3, SWOT Analysis

Strengths	***Weaknesses***
▪ *Abundance of cheap resources* ▪ *Natural Scalability* ▪ *Self organising / maintaining* ▪ *Redundancy of resources according to demands* ▪ *Development platform* ▪ *Driver for broadband*	▪ *Security and Authentication* ▪ *Peer heterogeneity and high fluctuation rate in population* ▪ *Lack of successful business models / applications* ▪ *Lack of incentive mechanism* ▪ *Expensive inter-domain traffic for ISPs* ▪ *Insufficient QoS support*
Opportunities	***Threats***
▪ *Inexpensive Infrastructure* ▪ *Development and fast deployment of new services* ▪ *Lowers barriers to entry*	▪ *Illegal Content* ▪ *Security* ▪ *Inefficiency* ▪ *Instability* ▪ *Asymmetrical benefits (e.g. between customers and ISPs)*

6. Skype: An efficient peer-to-peer solution for voice over IP

6.1. Overview

In August 2003, Skype (Skype, 2006) launched a peer-to-peer network to offer a voice over IP service. After downloading the software, users with direct Internet connectivity can make voice calls to other Skype users on the Internet for free. Since March 2005, SkypeOut and SkpyeIn functions have been added to receive or to make calls to regular phone subscribers in the Public Switched Telecommunications Network (PSTN). Both features are sold at a charge as well as a voicemail service, forming a basis for revenue.

Skype is an impressive example of an efficient P2P application and its potential to spread globally over the Internet via a P2P overlay. In September 2005, Skype was acquired by Ebay in a several billion deal. At this time, Skype's statistics claimed that there are:

- more than 50 million registered users
- more than 3 million users being online with Skype at the same time at daily peak busy periods
- 42% European users, around 12% in North America and more than 20% in Asia
- 40 million voice call minutes being served via Skype per day, which corresponds to approximately 30 000 calls in parallel in the mean over a day.

Even if those figures are only partly confirmed by other sources (Vollenweider et al., 2005; Sullivan, 2005), Skype undoubtedly has established the most popular global VoIP network within two years.

6.2. Peer-to-peer network structure and technical aspects

Skype maintains a central registration server, but all other functions for searching the user directory and setting up calls are implemented via a decentralised P2P approach. The P2P network includes a second hierarchy level of super nodes. The developers of Skype could bring in experience from their previous involvement in the launch of KaZaa, one of the most popular clients used for file sharing in the FastTrack network. The P2P nature of the Skype solution reduces the need for establishing expensive infrastructure to a minimum. Although the software is proprietary and not public, some main properties of the system have been tested in a study by Baset and Schulzrinne (2004):

- Skype uses a wideband codec covering a frequency range from 50 – 8 000 Hz. This may even go beyond the sound quality of PSTN, which is restricted to a 300 – 3400 Hz band. The voice codec usually generates an IP data flow of 30 – 40kbit/s, which may be increased up to 130 kbit/s for improved quality, when the access rate and capacities on the transmission path allow for a higher rate.
- Skype enforces privacy using 256-bit symmetric end-to-end encryption based on AES (Advanced encryption standard). Encryption keys are negotiated under a public key encryption based on 1536 or 2048 bit RSA. This also goes beyond usual regular

phone calls, although a comprehensive comparison of the security level is difficult for a proprietary protocol.

- Firewall and NAT traversal is achieved, which makes Skype available even through protected enterprise networks. Skpye seems to use a variant of the STUN protocol (Rosenberg et al., 2003) to determine, whether a user is located behind a firewall and then tries to use open TCP ports via a relay station for connections over a firewall. An arbitrary peer from the network pool is chosen as an intermediate relay station.
- Skype supports instant messaging and conferencing. In addition, video conferencing solutions are intended to run over Skype.

6.3. Business Implications

The success of the Skype VoIP solution gives insight into business opportunities for P2P networks. Skype uses a service based approach, while additionally providing free worldwide PC-to-PC communications to attract participants to the network. Skype is easy to install and only requires a PC with sound card and a headset or speaker microphone.

In addition, SkypeIn, SkypeOut, and voicemail are offered at a charge, where SkypeOut is the main source of revenues and used by a million customers according to an announcement by Skype in March 2005. Selling equipment like cyperphones and handsets is another contribution to Skype's revenues.

The costs for deploying the P2P solution are estimated to be low, with most components and functions being implemented in a distributed system using resources on the participating peers, except for a registration server. Furthermore, termination agreements with PSTN carriers around the world eliminate the need for local gateway servers. In contrast, non-P2P VoIP providers have to deploy centralised servers and network resources, rendering the solution uncompetitive.

In addition to proprietary VoIP and instant messaging approaches, standardised architectures exist, including VoIP in a multi service environment for next generation networks. This can be accomplished with the SIP (session initiation protocol) framework of the Internet engineering task force (IETF). Other standardisation bodies (3GPP, ETSI-TISPAN, ITU) are working on an IP multimedia subsystem (IMS) architecture over SIP as a major integrated building block. IMS aims at providing end-to-end services over homogeneous networks (fixed broadband networks, WiMAX, WLAN and cellular mobile networks). Nevertheless, service integration by those standardisation approaches tends to involve much more complex structures, e.g. introducing session border controllers at each network boundary.

While traditional voice operators work on solving technical issues P2P overlay networks, like Skype, are building impressive customer bases and becoming an attractive partner for mobile and other network providers that wish to extend their service portfolio. Development within P2P is fast paced and with infrastructures growing in correlation to customer number, national telecoms relying on long term standardisation work are facing hard competition.

Furthermore, Skype does not offer specialised services for business customers. Since it is observed that 30% of the Skype users also use the service at work (Vollenweider et al., 2005) this could be another opportunity for profitable service extension.

6.4. Impact of Skype on ISP revenues

The impact of Skype's VoIP solution on operators is mainly in the form of customers shifting from traditional telephone services to VoIP. While the result is declining revenues for long distance[11] calls in the PSTN, the shift is a driver for broadband adoption and may induce existing customers to upgrade their broadband connections.

In a market study by Evalueserve in January 2005 (Vollenweider et al., 2005), Skype is expected to expand to 140 – 250 million residential users until 2008. The Evalueserve report compares the development of a free VoIP solution attracting 140 million users to the expected development without such a solution. By analysing the effect on actual operators (Verizon, Swisscom) the study concludes that market situation will be different in the US market as compared to Europe.

Skype is expected to have more impact in the European market, where revenues are still higher for long distance calls and where Skype already has a large customer base, than in the USA. Among general conclusions of the analysis of impact on ISP revenues in 2008 are:

- decline of revenues in long distance calls due to reduced customer base,
- decline of revenues in long distance calls due to reduced prices; a decline from 0.24 to 0.15 USD/min is assumed in the USA and the same decline in CHF/min for Switzerland,
- decline of revenues in local calls (only relevant in Europe),
- decline of revenues in wholesale and

[11] Local transmission is also affected but not as much as long distance since VoIP services usually require local termination in PSTN networks

- decline of revenues in mobile telephony, where roaming costs can be avoided by shifting transmission paths to the Internet backbone.

As final remarks, offering VoIP service does not raise legal issues like the problems of copyright infringement with file sharing. However, VoIP is presently developing without regulation, which may change with the development and market share of VoIP. Support for locations specific e-mergency calls, legal interception and other aspects may then be required for VoIP in the same way as for traditional phone services. We conclude that although P2P applications can have major impact on telecoms by re-placing traditional services, they will compensate by continuing to increase the traffic volume and usage of broadband access and transport services.

7. Server initiated peer-to-peer service proposal

In recent times content providers

In this Section we will demonstrate the benefits of a new content distri-bution service utilising peer-to-peer overlay networks. We call the service Server Initiated Peer-to-Peer (SIP2P), building on existing work from (Sigurdsson, 2005). SIP2P combines the client/server and peer-to-peer paradigms with emerging subscription feature of RSS (Realy Simple Syn-dication) to form a novel distribution system. To evaluate the concept we use empirical data gathered at the Danish National Broadcaster (DR) to simulate efficiency. The traces used are collected from the web-based news on demand service “TV Avisen” throughout April 2005, which according to The Danish Media Organisation is the most popular web service in Den-mark. These traces represent roughly half a million successful requests and incurred transmission of 4.7 TB of data, see Table 4.

Table 4, Broadcasting Statistics

Log period	1 April 2005 - 30 April 2005
No. of successful requests	476.295 requests
Total no. of bytes sent	4,70 TB

7.1. The Challenge

Even with significant technological advances, a common phenomenon of streaming video applications nowadays is repeated freezing, buffering and defects (Sripanidkulchai et al., 2004a, 2004b). As a result, streaming applications are limited, mostly to live broadcasting where the users are willing to sacrifice the quality in order to get timely information. Even in cases when high quality distribution is technically available, the investment and the transmission cost of offering large scale high-quality video content renders them unfeasible.

7.2. Motivation

The motivation of our work is simple. We envision a system where users can subscribe to content and the quality they desire. The content gets delivered through a peer-to-peer network and the user gets a notification as soon as he/she can consume the content in a problem-free fashion. If the user does not wish to consume the content immediately upon notification, the content gets stored locally for later consumption. In the TV Avisen example this would mean that the Danish Broadcasting Corporation could offer high quality to new subscribers as soon as it becomes available for the fraction of the cost of traditional server based streaming.

7.3. The Basic Concept

The basic idea of SIP2P is based on building a peer-to-peer overlay network capable of distributing high quality multimedia content that end users have in beforehand subscribed to. The concept is based on changing the role of the streaming server in the current service to a seeding server, which transmits a few copies of the content to a subset of supernodes and then only communicates control messages between participating peers that take care of transmitting the actual content among themselves. Instead of deploying expensive high capacity servers as in traditional streaming services, SIP2P suffices with low capacity seeding servers to disseminate a few copies of legal content into a P2P network. Peers can then be motivated with monetary rewards, to share their, often underutilised, resources to distribute the content.

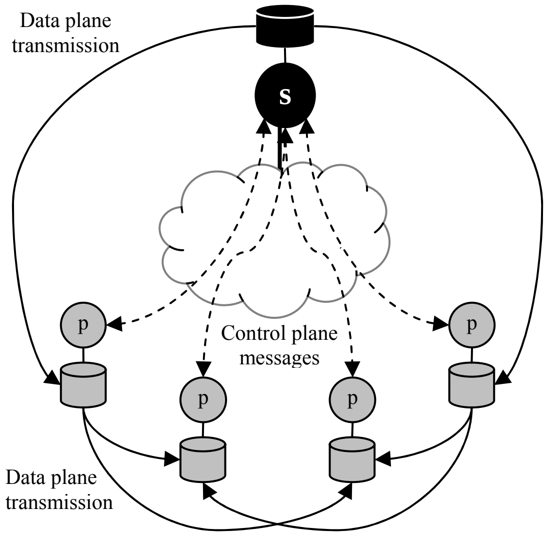

Figure 1, Conceptual Model of Server Initiated Peer-to-Peer (SIP2P)

7.4. Experimental Results

The authors have already shown in an experimental study that in a VoD service, assuming a $5 rental price, that the possible discount/profit per rental of SIP2P over traditional streaming services is 15-18% (Sigurdsson, 2005). However, in this experimental study we assume that content is free to the consumers but examine cost saving/increase in quality for the service provider. We assume that the DR is subject to capital expenditure for new hardware and operational expenditure related to transmission cost, both linearly related to maximum capacity and called Total Cost of Ownership (TCO).

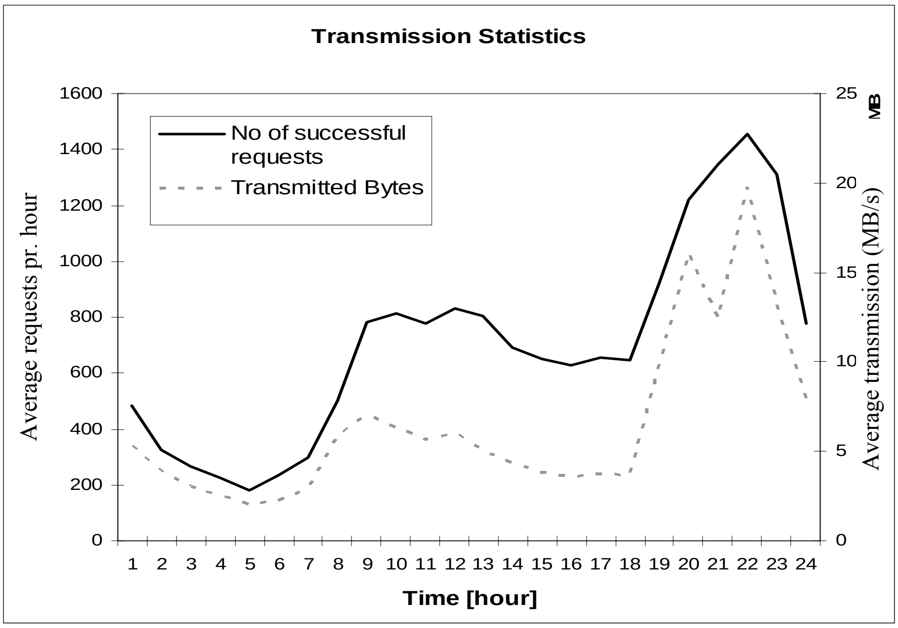

Figure 2, Transmission Statistics for “TV Avisen “ a popular news on demand service in Denmark

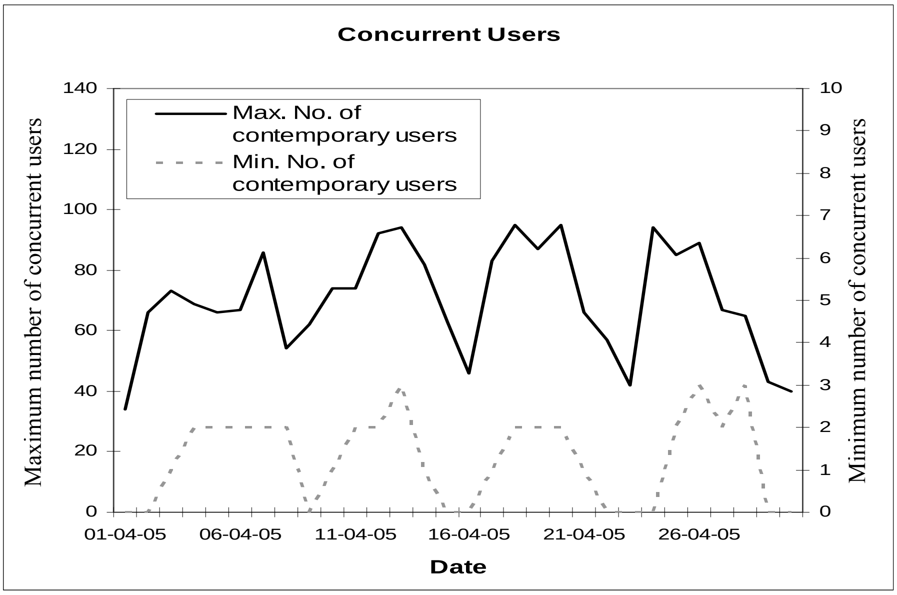

Figure 3, User Statistics for “TVAvisen” a popular news on demand service in Denmark

Figure 2 and Figure 3 illustrate transmission and user statistics for the period. Dividing the transmission rates by average number of concurrent users throughout the period yields an average streaming rate of 240 kbps.

Assuming 2 Mbps streaming rate required a for high quality service, DR could expect an eightfold increase in capacity, which again can be interpreted as an eightfold increase in TCO.

Lets now examine the case for a 2 Mbps streaming service using SIP2P. We assume a 10% seeding percentage and neither an inducement factor nor a opportunity cost for participating peers. A comparison of the relative TCO for the three scenarios is depicted in Table 5.

Table 5 Service Cost Comparison

	Traditional	Traditional	SIP2P
Rate	240 kbps	2 Mbps	2 Mbps
Relative TCO	1	8,3	0,9

What the experimental study suggests is that DR could serve the same number of customers as they currently serve, while improving the quality by an eightfold higher streaming rate at 90% of the cost.

Regarding future directions in the convergence of radio and TV broadcasting with Internet applications, an interesting field trial has been carried out by the BBC for testing their integrated media player (iMP) (BBC, 2006). They used a peer-to-peer networking approach to make a part of their TV and radio programme available for watching and viewing for seven days after the broadcast transmission date. The software included a digital rights management system that made downloads expire after seven days and to invalidate further transfers of the data via email or disc.

A field trial included 5000 registered users from UK in a time frame from November 2005 until February 2006. Several hundred hours of TV and radio programme were offered for P2P download. While being restricted to rights-cleared productions, the offered programs appeared to be attractive to the involved users.

The field trial gave BBC hints about on-demand user behaviour. They reported shifts being observed during the field trial regarding the popularity of niche programmes and peak viewing hours as compared to usual assumptions. For the TV viewers and radio listeners the opportunity of on-demand selection according to individual preferences can be an attractive next step towards an integrated IPTV and multi media future.

8. Conclusion

Peer-to-Peer networks have evolved from being a marketplace for illegal content to becoming a platform for a wide spectrum of mainstream applications. There is an increasing tendency to use peer-to-peer applications for real-time communications and, as Skype proofs, efficiently implemented P2P aided applications can offer a robust and scalable alternative to server based solutions for a fraction of the cost.

Given the potentials of P2P technology, the immediate question becomes where and when to apply P2P? To answer this question the paper has studied P2P technology through technical and economic analysis. The technical analysis described the evolution of P2P overlay networks and applications, illustrating the different alternatives. The study highlights the need for careful selection of technical specifications matching specific application requirements as a precondition for efficient usage of the resources and distribution schemes available.

In the economic study, we have developed a framework to analyse the use and sustainability of peer-to-peer networks in competition with alternative "traditional services". The analysis was based on calculating and comparing the utility that users and service providers get from using and offering the two types of services. The study has revealed some of the underlying conflicts of interests experienced in early file-sharing applications and the fundamental lack of new business models representing a complete revenue model accounting for all players involved in content distribution.

To sum up the potentials and challenges that P2P technology faces we have applied a SWOT analysis, highlighting the issues that need to be taken into consideration in the design of next generation P2P based applications.

To demonstrate the use of P2P we have carried out case studies of Skype as a well known example of efficient use of P2P technology reaching global market leadership in VoIP within less than two years. Furthermore, we have demonstrated how the use of P2P has the potentials to increase the streaming quality level of Danish Broadcast Corporation without increasing the investment or transmission costs.

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