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Peer-to-Peer Aided Streaming in a Future Multimedia Framework

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ABSTRACT

In this paper, a novel conceptual model called Server Initiated Peer-to-Peer (SIP2P) is presented, which combines the client/server and peer-to-peer paradigms into a hybrid distribution system suited for a future multimedia framework. Instead of deploying expensive high capacity servers as in traditional streaming services, SIP2P uses low capacity servers to disseminate a few copies of legal content into a P2P network. Peers are then motivated with monetary rewards, to share their, often underutilised, resources to distribute the content.

The paper presents a hypothesis that states the conditions for SIP2P to prevail in such a future framework. To prove the hypothesis, economic methods of calculating utility are presented both for peers and operators. Based on the calculations of utility, the economic efficiency of SIP2P over traditional streaming is examined and guidelines for adjusting peer reward presented.

1. INTRODUCTION

In recent years, rapid Internet growth and digitalisation of audio / video (AV) content has enabled a wide range of multimedia applications for residential users. Consumption and demand for content has been reinforced by the availability of broadband connections capable of delivering high quality continuous media. Content providers have traditionally used two approaches to meet this demand and distribute content over the Internet: direct and third-party [3]. In the meantime users have built up communities of their own, based on the peer-to-peer (P2P) paradigm. These networks take advantage of the immense number of often underutilised end systems, by storing increasing amount of content locally at peers.

However, the problem with these P2P networks is that they are mainly used to exchange illegal content. If there was only legal content, the only reason to use a P2P network would be if it could be used as a distribution network in a more efficient manner than other available distribution networks. Therefore P2P networks in their current form are only an intermediate step in the development of a future multimedia infrastructure.

Currently there is active research into what has been called the future multimedia framework [15]. This should encompass all aspects of consumption, distribution and commerce with digital content. To examine the role of the P2P concept in this framework, this paper will describe a proposal for a novel conceptual model for P2P aided streaming and present an economic analysis of its attractiveness versus traditional distribution systems. The structural design is a hybrid of concepts based on Next Generation Networks [17, 18, 19] and enhanced P2P architectural models [1, 2, 7, 11, 12, 13, 16]. The analysis is inspired by selected methods presented in recent, economic oriented, research literature [3, 4, 8, 10].

The rest of the paper is organised as follows. First the background, current issues, and future of P2P networks is presented in section 2. In section 3, the applicability of P2P aided streaming in a future multimedia framework is examined. In section 4, a conceptual model for P2P aided streaming is developed and its components described. Section 5 presents an economic analysis of the utility of both participating peers and operators, ending with a simulation of a fictitious Video on Demand (VoD) system. Finally, Section 6 will end the paper with conclusions and future work.

2. BACKGROUND

The original Internet was fundamentally designed as a peer-to-peer system [9]. In the early Internet, any two machines could unrestrictedly send packets to each other. It was used as a cooperative platform for researchers that exchanged information in a decentralised way. During the 1990s, scaling and commercialisation led the Internet to become increasingly client/server oriented, with millions of consumer clients communicating asymmetrically with a set of few relatively privileged servers. In the current Internet, clients are most often shielded and unreachable behind firewalls and network address translators.

2.1. THE RISE OF P2P 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 to reproduce and share their content over the Internet. Without contact with the original content provider, users started communities based on the concept of sharing their own content and in return getting access to the content of everybody else. While violating the intellectual property rights of the producer, this provided a platform for millions of users that now 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 such as Napster and Gnutella.

As the popularity of P2P networks grew, the worries of content 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 the P2P networks. This resulted in lawsuits, which although successful in closing Napster gave rise to the development of advanced P2P networks that have not yet been closed. Today, millions of users are actively using P2P networks to share content.

2.2. DIGITAL RIGHTS MANAGEMENT

The content that circulates in the most popular P2P networks mainly consists of audio, video, and applications that are protected by Intellectual Property Rights (IPR). However, in the absence of Digital Rights Management (DRM) there are no means to ensure lawful usage or restrict reproduction.

Due to the lack of widely adopted DRM solutions, content providers have been reluctant to distribute their content over the Internet. This has led to a mismatch in the supply and demand of services for legal content on the Internet. Much of the unmet demand has in the meantime been met with illegal content as the only viable solution. Some maintain that this free introduction to music and applications over the Internet only simulates subsequent sales while content providers argue that it is the reason for declining reported sales. Most however agree, that the current mass distribution of content in P2P networks is illegal and that legal distribution would be more desirable.

There is a wide disagreement about the extent, form, and role of DRM in future multimedia frameworks. With DRM solutions emerging that meet the requirements of content providers, services with legal content are appearing and will presumably evolve and proliferate.

2.3. THE END OF P2P NETWORKS AS WE KNOW THEM

Assuming that the future will bring a future multimedia framework that will offer 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 option for content delivery. It then has to compete on an even ground with other methods of content delivery. Estimating the economic efficiency and competitiveness of P2P aided streaming as a legal distribution network will be the focus of the rest of this paper.

3. APPLICABILITY OF P2P AIDED STREAMING IN THE FUTURE MULTIMEDIA FRAMEWORK

There have been different proposals for the future media framework such as MPEG-21 and Microsoft's Windows Media 9. The driving factors behind the development of these frameworks are the externalities to be gained from a potentially enormous common interoperable marketplace. For such a framework to be adapted it has to attract users with usability and content owners with security. If both requirements are fulfilled, content providers and consumers can exchange goods. If there is a seller, a product and a buyer that agrees to his conditions and price, business can take place.

Analogous to rental of movies from a traditional video rental shop, the electronic consumer expects content to be available when he wants it and in the format he wants. If the seller can not meet the quality of service that the consumer expects, the customer will generally choose not do future business. However, there might however be consumers that are willing to lower their demands if they get the product at a better price. This is again analogous to a traditional video rental shop that might, for example, offer discounts if movies are rented in the morning and returned again the same day before the evening peak hours.

Using this reasoning to describe the usage of P2P aided streaming in a future multimedia framework, I present the following hypothesis to describe the necessary conditions in which commercial P2P aided streaming can prevail, namely:

> ***Hypothesis***
> *P2P aided streaming will only prevail if it offers higher utility to both peers and service providers than traditional streaming services, given the same quality level.*

This makes sense as the consumer would not pay a higher price for P2P aided streaming if it offered lower quality than traditional streaming. The provider on the other hand would not use P2P aided streaming unless it was less expensive to deploy unless it provided new market opportunities. In both scenarios the question of how to persuade peers to contribute resources arises.

3.1. COMPETITIVENESS OF P2P AIDED STREAMING

Effectiveness of data transmission services has typically been measured in how well they utilise constrained capacity in congestion prone networks [3]. The design and pricing of data transmission services has therefore typically focused on how to design price-service schemes that optimally allocate capacity. Development and increased capacity of both backbone and access networks in recent years, has however 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 steps of increasing maximum available bandwidth, or volume prices for measured extra-domain traffic. Both these pricing schemes increase P2P attractiveness 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.

If P2P networks do not incur extra transmission cost for consumers, usage will be based on content price, quality, and necessary resource contribution. To meet these requirements I propose a novel framework where quality is ensured with efficient error recovery [2, 11, 13] and users are stimulated to contribute resources

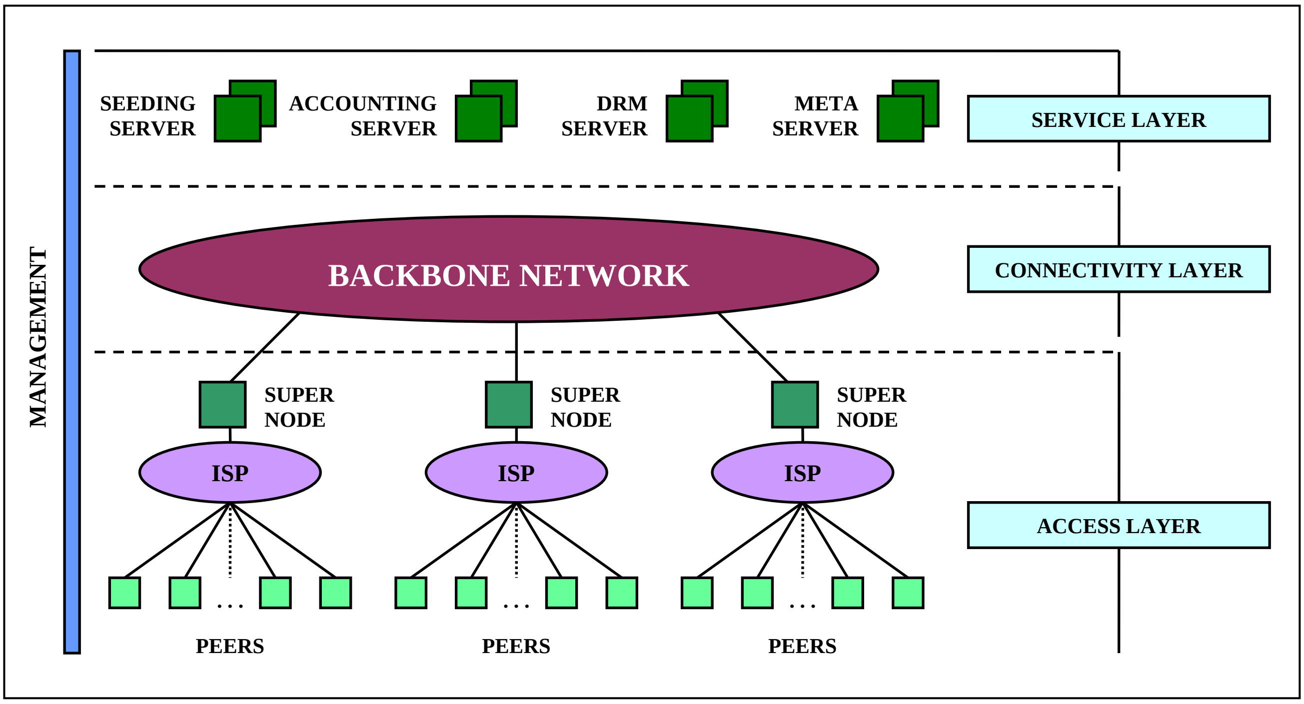

Figure 1: Conceptual Model of P2P aided streaming the future multimedia framework

by receiving monetary rewards or earning discounts on content. The remainder of the paper describe a conceptual model that meets these usage requirements and examine if the economic conditions of the hypothesis are met.

4. Conceptual Model

In this section I will develop a novel conceptual model called Server Initiated Peer-to-Peer (SIP2P) for content delivery in a future multimedia framework. The structural design is a hybrid of concepts based on Next Generation Networks [17, 18, 19], where the network architecture is decomposed into three decoupled functional layers, and the P2P architecture that supports a scattered decentralised network of peers [7, 11, 12, 13, 16]. To motivate peer participation and overcome the "freeriding" problem [5, 6] I propose a scheme based on accounting where peers get monetary rewards or discounts on content based on their contribution of resources.

The model consists of the following entities:

Peers

A peer (p_i), is an entity that interacts with the framework. $\mathbb{P} = \{p_1, p_2, \dots, p_N\}$ denotes the set of all peers in the framework. Each peer controls his level of interaction with the framework through two parameters: (1) r_j (in Kbps), the rate at which peer p_i consumes digital item j; (2) S_i in Kbits, the total contribution that peer i has made to the system. Peers are allowed to have as asymmetric interaction as they choose, but get discounts or rewards depending on their contribution in Kilobits. This opens up the possibility of peer distribution "sub-contracting" if some peers value the reward high enough. The service provider controls the reward.

Seeding Server(s)

The *seeding servers* seed multimedia content into the system [4, 16]. The name seeding server (in contrast to media or streaming server) is used to indicate that their main functionality is to initiate the dissemination of media files into the network, and not serve clients directly.

Accounting server(s)

The *accounting server* has two functions. Firstly, it registers and charges for transaction or Use of content. Secondly, it registers client contributions to network transmission.

DRM Server (s)

The *DRM server*, takes care of admission control and acts as a Clearinghouse and license server [20, 21]. When a peer tries to view content, a local *DRM tool* [15] examines the rights associated with the content to see if the peer has the necessary rights (licence) to view it. If the peer does not, the local DRM tool contacts the *DRM server* for security and trust audit [15]. If the peer needs to purchase a license, the DRM Server redirects the peer to the *Accounting Server*.

Digital Item

A *Digital Item* is a structured digital object with a standard representation, identification, and metadata within the framework. [15] Each Digital Item is characterized by a size in bytes, and can be consumed at a rate represented by bit rate $r \leq R^{max}$ in Kb/s.

Meta Server (s)

The *Meta Server* contains information about all Digital Items in the network. The Meta Servers, along with *Super Nodes* aid in searching and store information about peer participation and location of digital items available in the framework. Note that the meta server only contains information *about* the content and **not** the content itself. If peers contribute a new digital item into the network it is registered at the Meta Server and subsequently made available through the accounting server. Giving users the possibility of registering new content into the framework, opens up new business opportunities such as distribution of user generated content and acting as a distributed storage network, since contributors can control access and charges for content, enforced by the DRM and accounting servers.

Super Nodes

The Super Nodes are optional scaling entities that distribute the load on the Meta Server(s) and bring information about content closer to the peers, improving the response time and robustness of the framework. The reasoning behind Super Nodes is described further in [7].

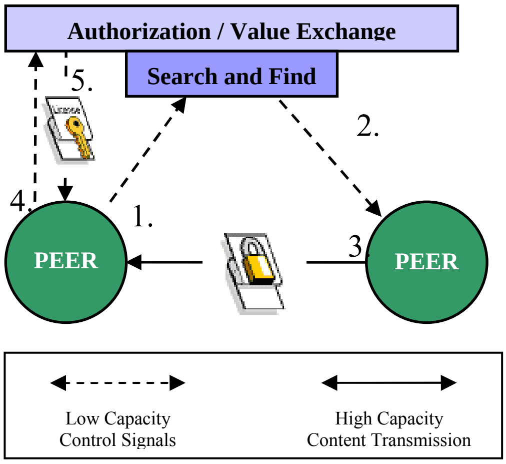

Figure 2: Flow of information associated with P2P aided streaming in SIP2P. DRM protected content is sent upon request after search through a meta server. Consuming peer contacts DRM server to get license to view the content.

5. Economic analysis

This analysis is based on a 'holistic' approach [22, p. 10], where the interaction between peers and service providers in the framework is governed by the utility that both obtain from participation. I assume that each digital item can be consumed in discrete amounts, for example these could be of different quality resulting in different utility and cost. I assume that the quality level is linear and directly proportional to the Kbit rate per second r, at which the Digital Item is consumed. The utility that 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 $v_j(r_j)$. To control the reward that the peer p_i gets from sharing his resources, I introduce the inducement factor α. This factor, times the total Kilobits that peer i has served S_i, represents a monetary reward. When users contribute resources, they can not use the same resources during that time. Assuming that this incurs negative utility for peers, I introduce an opportunity cost factor β. I 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.

5.1. MAXIMISING PEER UTILITY

I 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_j^{SIP2P} equal to the price of the same Digital Item delivered through traditional streaming v_j^{trad}, and decides upon an inducement factor α, each peer is faced with the problem of optimising his own utility through equation 1.

Equation 1.

$$U_{i,j}^{SIP2P} = \max\left\lfloor u_i(r_j) - v_j^{SIP2P}(r_j) + \alpha S_j - \beta S_j \right\rfloor$$

From Equation 1, I deduce the peer utility for traditional streaming services by setting α=β=0.

Equation 2.

$$U_{i,j}^{tra} = \max\left\lfloor u_i(r_j) - v_j^{tra}(r_j) \right\rfloor$$

Given that the quality level is the same in both systems and that $v_j^{SIP2P} = v_j^{trad}$, comparison shows that the total utility of SIP2P aided streaming is only higher than that of traditional streaming 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 SIP2P aided streaming than from using traditional streaming and will therefore choose traditional streaming. As described before this assumes that the service quality level is the same in both systems. This can be considered a proof of half of the hypothesis of section 3.

A special case of Equation 1 arises when we look at the current P2P networks where no fee is paid for content and no reward is given, i.e. p_j= α=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 (or cost for content is introduced) participation becomes less attractive.

Table 1. Symbols used in the economic analysis

Symbol	Description
α	Inducement factor
β	Opportunity cost factor
γ	Depreciation factor
p_i	Peer i of N, 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}	License fee
L	Total number of digital items served
$I(L)^{tra}$	Investment required in a traditional system to serve L
I^{SIP2P}	Investment required in a SIP2P system to serve L
$O(L)$	Operational cost for a system serving L

5.2. MAXIMISING SERVICE PROVIDER'S PROFIT

I assume that service providers are rational, autonomous profit-maximising economic agents. I 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 streaming services and SIP2P aided streaming services is a function of the number of digital items served (L) by the systems as described in Equation 5 and 6[1].

Equation 5.

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

Equation 6.

$$C^{SIP2P}(L) = q^{lic}(L) + O^{SIP2P}(L) + \alpha \cdot L \cdot R + \gamma \cdot I^{SIP2P}$$

In the equations, $q^{lic}(L)$ represents license fee for content L, O(L) is the operational cost which is considered to be the same in both systems (i.e. $O^{trad}(L)=O^{SIP2P}(L)$), 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 SIP2P system the investment cost is fixed, but for the traditional system it is a step function, representing required steps of investment to support customer base demand of L (i.e. 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.

I assume that traditional service providers can always meet increased demand by investing in additional resources (I ignore the lag in supply and demand caused by purchase and installation of additional resources) and that SIP2P service providers can increase customer base and therefore supply by adjusting their α. 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 (as the retail price in both systems is the same) and since the license fee and operational cost are the same.

Equation 7.

$$\text{Decision} = \begin{cases} Traditional, if: \gamma I(L)^{trad} \le \alpha lR + \gamma I^{P2P} \\ SIP2P \quad , if: \alpha LR + \gamma I^{P2P} < \gamma I(L)^{trad} \end{cases}$$

If the investment cost is proportional to the number of clients the system has to serve, the advantage of P2P becomes evident since a seeding server only has to serve a small percentage of all peers, whereas a streaming server has to serve all clients. With investment cost proportional to clients served, $I^{P2P} << I_l^{tra}$, and the P2P operator will have the cost savings of $(\gamma \cdot I_l^{tra} - \gamma \cdot I^{SIP2P})$ to adjust based upon α. To be profitable, the SIP2P provider has to adjust α within the limits of Equation 8. The SIP2P service provider can use tatonnement [22] to adjust the price and the inducement factor to obtain the operative equilibrium he chooses. For simplicity, I assume that he only adjusts the inducement factor, but generally he could attract more customers from traditional services by lowering the price, and increase capacity by raising α.

Equation 8.

$$0 \le \alpha \le \frac{(\gamma I_l^{tra} - \gamma I^{P2P})}{lR}$$

Equations 7 and 8, shows that P2P aided streaming 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. I have thereby finished proofing the hypothesis of Secion 3.

To investigate the properties of Equations 7 and 8 further I will conclude this Section with a simulation of a fictitious Video on Demand (VoD) system.

5.3. VIDEO ON DEMAND SIMULATION SERVICE

To investigate the validity of the theories presented in this paper and the effect of the

[1] for simplicity difference is licence fees and cost between digital items is disregarded

Table 2. Simulation of Investment cost in a VoD system based on Traditional vs. SIP2P aided streaming. The Profit/Reward row shows the estimated savings per rental from using SIP2P.

Concurrent users	**100**	**200**	**300**	**400**	**500**	**600**
Per day rentals	300	600	900	1.200	1.500	1.800
Per year rentals	109.500	219.000	328.500	438.000	547.500	657.000
Traditional						
Investment	$500.000	$1.000.000	$1.500.000	$2.000.000	$2.500.000	$3.000.000
Depreciation cost	$100.000	$200.000	$300.000	$400.000	$500.000	$600.000
SIP2P						
Investment	$100.000	$100.000	$100.000	$100.000	$100.000	$100.000
Depreciation cost	$20.000	$20.000	$20.000	$20.000	$20.000	$20.000
Profit/Reward	$0,73	$0,82	$0,85	$0,87	$0,88	$0,88

equations presented I will present a fictitious service where a service provider is starting a regional high quality VoD service. He has invested in the development of an application with a user interface where client can easily find content, scenes, and additional information about available movies by searching supported

by a metadata server. Two subcontractors have made separate tenders for content distribution

networks, one based on traditional streaming and the other on SIP2P. After independent consultants determined that the quality of service and error resilience was identical, the service provider wants to make a profit comparison of the two distribution networks.

I assume that the cost of serving each concurrent stream is the same for the servers in both systems. One traditional server can serve 100 concurrent users at the price of $500.000 and the SIP2P seeding server will have the capacity to serve 20 concurrent users with the total investment of $100.000 in all SIP2P servers. The operator expects its maximum customer base to be 600 concurrent users and that the average consumption per day is 3 times the maximum concurrent users all days of the year. Assuming 20% yearly depreciation, Table 2 shows the operator's cost of both SIP2P and traditional streaming services.

Given identical operational cost in the two systems, the operator can save the difference in depreciation cost of the two systems by choosing SIP2P, and can make a profit / reward to peers with up to [Profit / Reward] for each rental. If we assume $5 rental price the possible discount/profit per rental of SIP2P over traditional streaming services is 15-18%.

6. CONCLUSION

In this paper, a novel application-level content distribution architecture, called Server Initiated Peer-to-Peer (SIP2P) has been presented. SIP2P is based on a hybrid server/client, peer-to-peer paradigm where low capacity servers are used to disseminate and manage content in a P2P network. By analysing the utility of both the operator and the peers, conditions for prevailing were presented and proofed. Theoretical comparison of induced cost in traditional vs. SIP2P based architecture revealed the surplus of SIP2P, which can be split as profit for the operator and reward for peers. Finally, consideration of a fictitious service revealed this surplus to be 15% of rental price in a Video on Demand system.

6.1. FUTURE WORK:

In this paper, only a conceptual model of SIP2P was presented. This leaves many unanswered questions about the underlying technical implementation. For example, more work is needed on the selection of the underlying cooperative platform, coding and transmission, error resilience and interconnectivity. Lastly this paper presented methods of motivating peers with monetary rewards. The required amount of this reward, and the effect of changes must be examined better.

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