Mobile Peer-to-Peer in Cellular Networks

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Abstract

Mobility in Peer-to-Peer (P2P) networking has become a popular research area in recent years. One of the new ideas has been how P2P would suit for cellular networks. In this case, Mobile Peer-to-Peer (MP2P) presents not only technical but also business and legal challenges. The current 2G cellular networks cannot successfully support MP2P applications but the forthcoming 3G and WLAN networks offer interesting opportunities for P2P innovations. Due to the specific nature of cellular networks and devices, it is anticipated that both the MP2P architecture and also the most popular applications will differ notably from the existing, fixed network solutions. This paper explores how MP2P might be used in the 3G networks. Requirements are listed from a cellular operator's point of view, including both technical and business aspects, without forgetting the end user needs. In addition, a dedicated MP2P architecture is proposed and a couple of promising applications are reviewed. Finally, the future MP2P research topics are discussed.

KEYWORDS: Cellular, Mobile Peer-to-Peer, Mobile Proxy, Web Services

1 Introduction

Peer-to-Peer services, like file sharing and communication services, are well known for most of the fixed internet users. Extending the services for a cellular market of nearly 2 billion mobile handsets sounds tempting but so far there have been just a few research trials [1]. What is preventing P2P services from expanding for the mobile domain? Part of the reasons are technical but also business and copyright questions play a key role here. In this paper the main barriers are tackled and remedies to problems are given.

Most of the cellular operators consider Peer-to-Peer services as a threat that can jeopardize the existing profitable business and should be resisted by all means. Skype Internet Telephony service [2] is a good example of the P2P communication service that has conquered a considerable market share from the Voice over Internet (VoIP) markets. The copyright problems of the file sharing protocols, such as Napster and KaZaA, have not either helped the adoption of P2P services. On the other hand, with the boost of new 3G and WLAN networks, also the mobile operator camp has started to show signs of interest in MP2P services [3].

Is is possible to find a solution that would make both operators and end users happy? This is a crucial question, and not an easy one to answer. The operator viewpoint insists that the service must bring them money and there cannot be any legal risks incorporated. End user's major concerns are partly contradictory. Tolerable charging, easy to operate, high bandwidth and long battery life are clear requirements. But for both parties there are some good news, too. A mobile phone offers several unique advantages. Unlike a PC, a mobile is always with you and it is very personal device having your contact, calendar and profile information. Those enablers can be efficiently utilized in the MP2P applications.

Cellular MP2P hot topics are reviewed in detail in the following sections. In the beginning, section 2 discusses the requirements from a broad angle. First of all, the most critical challenges are presented. Typical P2P traffic characteristics are presented as a background for the 3G performance evaluation. Closely relating to that issue, the pricing questions are raised up. Finally a few technology and security concerns are listed. The latter part of the section elaborates the positive edge cellular networks can bring on top of the P2P services. The major topics here are the device features but also the networks have something new to provide.

Section 3 continues by proposing a new MP2P architecture that would optimally meet the requirements presented. The leading idea is that the fixed network should offer a mobile proxy for each mobile phone connecting to the P2P networks. This solution could also be tailored for the operators while keeping the full freedom for end users to select the service provider they want to use. The other major novelty introduced points to the Web Services, that combined with the P2P technologies might solve the problems with the P2P interoperability.

In section 4 a summary of sample MP2P applications is presented. Most of the existing applications have a strong network centric flavour, too, but true P2P features can be added to support the original idea. So far, the list of MP2P services is pretty short, but it can be anticipated that the open innovation will fulfil the empty space as soon as the basic MP2P infrastructure is on place. To conduct the theme to the end, a completely novel MP2P application utilizing the proposed architecture is described in detail. Finally, in section 5 conclusions are presented with further research proposals.

2 Requirements

P2P has not been considered yet a success story on the cellular domain, and there are a lot of good reasons for the negative evaluation. The most obvious barriers are listed in this section, but towards the end of the chapter, we draw out the positive signs of the picture.

2.1 Challenges

2.1.1 Traffic volumes

Peer-to-Peer networking is a superior data sharing technology compared to the tradional client-server model. In the fixed networks already over 60 percent of the traffic consists of P2P packets, and in the access networks portion is even higher. In traffic volumes this means daily a few tens of megabytes of video, voice, gaming and other multimedia data per user [4]. Fig. 1 shows one example of traffic distribution. It is clear that data amount will explode in the near future due to the ever growing popularity of the video applications. Some experts already claim that the Internet cannot support the increasing burden, while the others ensure that P2P will scale [6].

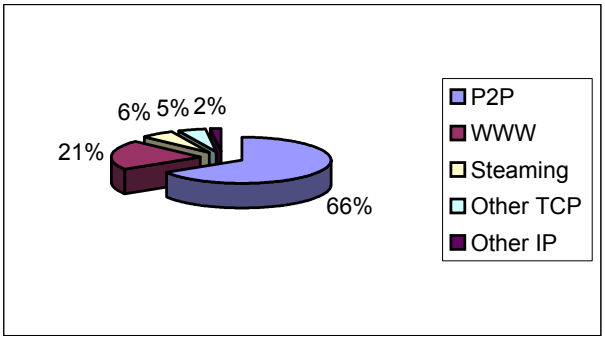

Figure 1: Traffic distribution in the fixed network [5].

2.1.2 Pricing

The current 3G networks are designed to carry mainly voice and data follows as a secondary service. The data charging scheme commonly used, is one of the major obstacles to MP2P services becoming widespread. Most of the cellular operators are still utilizing packet based charging that will definitely kill MP2P very quickly. The latest 3G data package offers are built on so called capped flat rate charging model where the final price has fixed and variable parts. If the consumption stays below the limit, fixed fee is applied, but if the limit is exceeded, a reasonably high packet based additional fee is requested.

Typical limits today are tight to 100 megabyte (MB) or even 1 gigabyte (GB) per month, with a price interval from 20 to 100 euros. In the longer term, the target price of 1 GB with 10 euro, or 1 MB with 1 cent, could be achieved. With cellular technologies this is close to the theoretical limit that can be dreamed of.

How much is then 100 MB or 1 GB? Three typical P2P service examples including bandwidth and capacity requirements are listed in the table 1. It is easy to see that with the lower budget MP2P is totally out of question. With the 1 GB allocation, audio could be within the average user's needs, but video would turn the picture soon upside down.

Content	Bandwidth	100 MB	1 GB
MP3 audio	128 kbit/s	100 min	1000 min
MPEG4 video	1 Mbit/s	13 min	130 min
MPEG2 video	5 Mbit/s	3 min	27 min

Table 1: Capacity requirements for P2P content [7].

2.1.3 Technology

Basically, the cellular networks might offer a reasonable pricing structure for the P2P services in the near future but a few other, more severe problems can arise. The battery technology versus the offered CPU speed, is improving fairly slowly, and without a major breakthrough, cellular device cannot meet the needs described above. Or to be more precise, the power might be enough for the consumption part, but not for being an intermediate node for the other P2P packets.

Cellular phones have also other well known restrictions. Their state and location vary fast that worsens the performance of the P2P protocols. There has been a lot of studies about how to improve the situation, but the challenges do exist. The last but not the least, 3G bandwidth will be limited for a long time. In the local area networks (LAN), service level with the maximum speed of 2 Mbit/s can be acceptable, but in the wide area networks (WAN), the typical speed drops to the level of 384 kbit/s. Even worse, the uplink direction of the data link can be a lot less depending on the radio network configuration and terminal capabilities.

2.1.4 Security

Peer-to-Peer as such expresses a wide selection of security concerns for the people using them. Adding the mobility feature will not decrease the worries, it is just the opposite. Without going to the details of the network security, it is clear that already the content security in the form of copyright violation is a huge challenge.

The internet way with mostly illegal content cannot fly on the cellular side, because operators cannot take the risk of illegal content being stored and shared by their systems. This means that the content protection with Digital Rights Management (DRM) must be solved. Record companies and related orgnizations have strongly accused P2P networks of the lower turnover [8], whilst the Creative Commons initiative [9] has brought another standpoint to the debat.

Secondly, MP2P inherits also a trust problem. How can we rely on the data shared? Obviously there are several answers for the question, but one of the most interesting alternatives is based on the metadata. That solution works well also in the cellular environment [10].

As the third topic, the privacy should be highlighted. P2P networks provide enormous amount of user data that could endanger the privacy in the wrong hands. With the cellular phones this is even more crucial theme due to the strong identity and location relationship of the user and the device. In the traditional P2P networks the information source is not normally revealed but in the MP2P it would be easy to extract. This is one reason why the MP2P users should enjoy a full anonymity.

2.2 Opportunities

2.2.1 Mobile device

The situation for the MP2P appears to be gloomy but fortunetely, mobile devices have several major advantages compared to the fixed network nodes. First of all, the mobile users are carrying the phones with them almost a day and a night. This usage pattern enables the offering of dynamic information through the mobile sensors. The addition of a high quality camera has been the first step to enable this progress, but various other important development phases are following. It has been estimated that by the year 2008, cellular phones might have already 2 GB mass memory as a standard feature. Also the user experience will be better: displays are becoming larger and in general, the graphical user interfaces (GUI) are easier and faster to use.

Regarding the trust challenge, the mobile phonebook provides a solid basis for the social network. You normally trust the people listed in your cellular phone and believe in the information they are sharing with you. You are also probably more willing to reveal your personal data with the neighboring social circle than with total strangers. In other words, phonebook can be utilized effectively in the MP2P Reputation Management.

2.2.2 SW tools

In addition to the hardware (HW) improvements, the software (SW) impacts will be even higher. The open application development environment backed by the open source communities will accelerate the innovation cycle by enabling a mobile to provide a good basis for the fascinating P2P services. It is essential that the mobile industry utilizes the common SW tools with the PC industry. By this way the development mass is the biggest possible, which will decrease the implementation costs. The mobile specific software will not be acceptable anymore, or otherwise we cannot consider the handheld devices to belong to the full members of the Internet.

2.2.3 Network services

The openness does not include only the terminal but also the network services supporting the phone functionalities. The well known *Walled Garden* approach must be rejected, and instead, the operators have to open the network application program interfaces (API) to maximize the network usage and the mutual benefit. The Location Based Service (LBS) has been a good example of the operator offering that has suffered a lot of the closed strategies. However, with the introduction of MP2P and reasonable pricing, the reception can be totally different.

The mobile operators might provide several other useful network services, too. Billing relationship and authentication service are valuable assets if we want to add a business plan on the MP2P. Without the secure and easy authentication system, charging becomes impossible. The Subscriber Identity Module (SIM) is here a competitive edge for the cellular operators. Trust and long customer relationship are also operator strengths. Would you give your credit card or personal profile information to some P2P network without any possibility to control where and how your data is used? On the cellular domain the security has always been one of the main concerns and a lot of effort to guarantee the process has been tailored in.

2.2.4 Connectivity

So far the connectivity has been the bottleneck cause operators have wanted to fully control the traffic. For example, on rare occasions they have offered a possibility to acquire a fixed IP address. Without the direct link between the terminals a P2P service cannot be implemented. Instead, the 3G standardization is heavily specifying Session Initiation Protocol (SIP) based IP Multimedia Subsystem (IMS) concept, that will allow the connections between the mobiles but still not from the Internet. The change of the position requires that all the mobiles are directly addressable from anywhere in the Internet.

3 Architecture

The arguments discussed above pose strict requirements for the successful MP2P architecture. The starting point here is that the MP2P solution should be built on the operator assets while at the same time promoting the open innovation with the maximum extent. Two major topics have been selected for the closer look, Mobile Proxy and Web Services concepts. Although both subjects are pretty new on the P2P research community, based on the latest development they deserve more attention.

3.1 Mobile Proxy

The dynamic nature of the Mobile ad hoc networks (MANET) has been studied a lot [11, 12, 13], but the interest on the cellular side has still been on the low level [14]. However, the clear need for the flexible MP2P architecture, where also the cellular phones can join, do exist. One very simple and straigtforward idea is to add each cellular phone a Mobile Proxy [15, 16] to the fixed network. A Mobile Proxy can be considered as a virtual peer connected to the P2P network, and it can fully represent the cellular towards the fixed and other mobile P2P nodes, even in the situation when the portable is out of coverage or lacking battery current. Fig. 2 shows the generic architecture.

The Mobile Proxy concept solves a wide range of MP2P problems. The mobility of the cellular phones is not an issue anymore, neither the physical restrictions such as bandwidth, CPU, memory, battery or coverage. This solution saves also transmission costs because we do not need to transmit all the bits over the expensive cellular network but the Mobile Proxy can stop, filter and aggregate the data gathered from the P2P networks. Also, the security features, like privacy, anti spam and virus protection, might be easily implemented in the proxy architecture.

Furthermore, the Mobile Proxy can simultaneously act as a *Virtual Storage* for the phone content. This is a useful feature when thinking about the use case of multi device ownership. The synchronization of the data between terminals and PCs is already now a problem, and it would be handy to keep

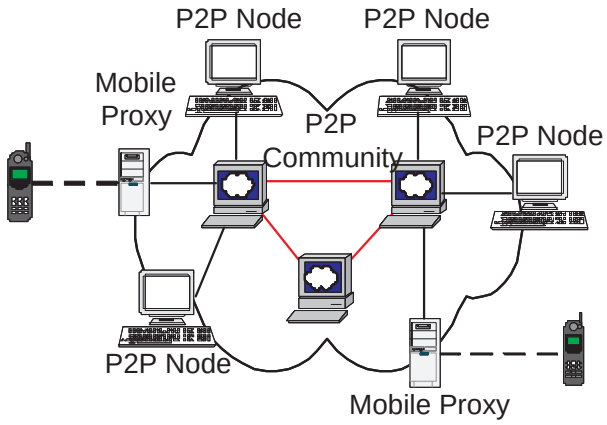

Figure 2: MP2P architecture utilizing mobile proxies.

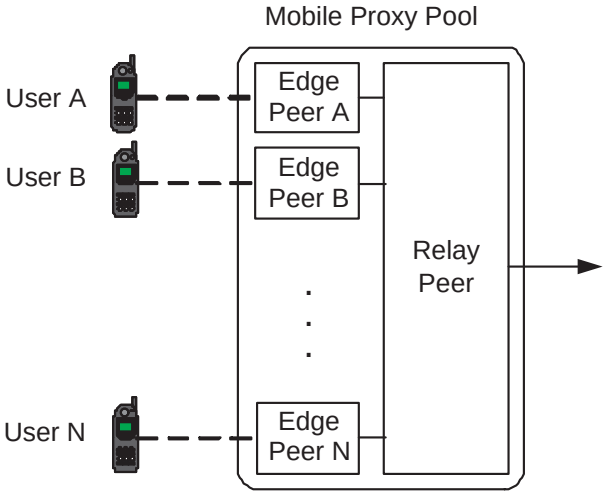

Figure 3: A Mobile Proxy Pool.

the phone directory, music and picture collections in the network, minimizing also the risk of loosing all the data during a device theft or failure. Depending on the needs, the content could be accessed and modified with a PC or a mobile, and synchronized automatically during the nights or manually anytime needed. A request from the network could also initiate an immediate upload procedure.

The internal architecture of the Mobile Proxy might vary depending on the design goals. A natural plan would be to allocate a bigger group of mobiles behind one physical proxy pool. Each mobile would have its own node name, visible also outside of the proxy, but the common functions could be provided by the master node. The last one can also be considered as a Relay Peer [17], whilst the virtual mobile nodes are called Edge Peers. Fig. 3 depicts a proposal for the internal structure of the proxy pool.

The combined proxy pool would open interesting visions. The platform enables an easy access to a huge database. Data sharing and search functions, both from the network and between the mobiles, could be implemented efficiently. Due to the centralized architecture, cellular operators would be very interested to host and manage Mobile Proxies for their customers. Even the solution might in the short term decrease the data traffic over the air interface, in the longer term the positive effects would outclass those concerns. In short, the solution would give a big boost to the data consumption. Operators would get new income from the Virtual Storage service, and also the advertizing possibilities among the cellular community could become lucrative.

To promote the full competition, proxies should be available from various service providers, and the selection of the service host should be totally free. Actually, cellular customers might belong simultaneously to several proxies that could be chosen based on the role, varing from the time of work to the private life hobby clubs.

IMS has been considered as an operator driven P2P solution. It allows the P2P connectivity but lacks some important features that are typical to native P2P networks. The major obstacle is that you cannot access the mobile memory from the Internet. However, with the Mobile Proxy solution this barrier could be safely bypassed. This means that all non dynamic data can be loaded directly from the proxy memory and the dynamic requests can be redirected to the phone itself, under the privacy rules defined in the proxy.

On the other hand, IMS has some advantages in the portfolio. It utilizes a standard SIP protocol, defined by the IETF, and that can be seen as an asset compared to the proprietary P2P protocols. In addition to the basic communication solution, IMS provides also additional services such as Presence and Push over Cellular (PoC). The combination of the IMS and Mobile Proxy pool could be an interesting system component, by providing the best parts from the cellular and internet domains.

3.2 WEB Services

P2P technologies and Web Services [18] are originally addressing different problems [19]. The first one enables an effective method to share data in one domain, while the latter one provides interoperability between different domains. On some areas, like security and service discovery, P2P and Web Services are overlapping, but basically the technologies can complement each other. In a nutshell, utilizing WEB Services with P2P brings clear advantages [20].

Uniform Resource Identifier (URI) is one of possibilities because no new naming system is needed. Web Services are also implementation agnostic ensuring a smooth interoperability over the different operating systems and software languages. Transport method can be selected as wished cause in addition to the HTTP, also FTP and SMTP are available. On top of the transport layer, Simple Object Access Protocol (SOAP) can be applied with a large group of extensions. Finally, the Web Services Framework (WSF) includes a complete set of supporting functions, including Web Services Desription Language (WSDL), Universal Description, Discovery and Integration (UDDI), and Liberty Authentication, Privacy and Security services [21]. In the near future the basic setup will expand with new extensions like messaging and charging definitions.

According to the Web Services terminology, a Web Services Provider (WSP) is the entity that provides services for the others and the Web Services Requester or Consumer (WSC) is the client part. Basically, all resources in the P2P

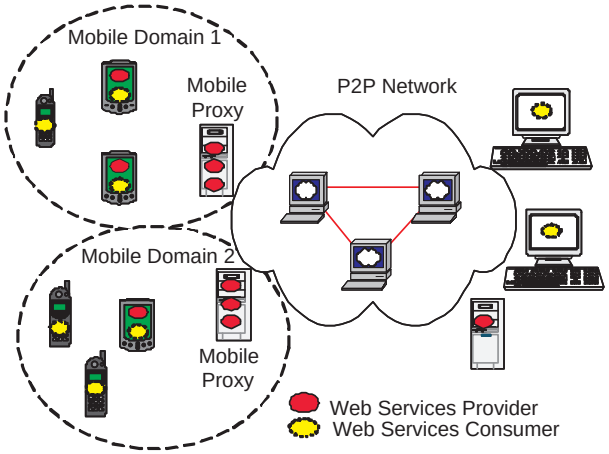

Figure 4: A Web Services Architecture in the MP2P.

nodes could be abstracted as Web Services entities. In the traditional P2P networks that would include music, videos, pictures, applications, CPU power and so on, but in the MP2P domain also new WSPs could be added. Through the Web Service interface cellular phones might open, for example, camera, phonebook, location and bluetooth data to the whole world or only to the selected user group.

Adding the Mobile Proxy to the WSF widens the scope. The vast majority of the static mobile content could be stored on the network pool, but like live camera views, dynamic data should be fetched directly from the cellular. As a conclusion, the Mobile Proxy pool can offer a fast access to the whole cellular community that could also be utilized by the search machines. A search use case such as, *"Find all the phones that are at the moment in the Madonna concert and capable to offer live pictures or videos"*, would become powerful and fascinating. The Proxy setup would offer another important feature relating to the anonymity. The relay peer hides the mobile WSPs behind the curtains and this way it might pull the data from any matching mobile without revealing the identity of the source. Fig. 4 illustrates the scenarious presented.

4 Applications

4.1 Open innovation

The innovation curve on the cellular services has been basically flat. Since the partly accidental invention of the Short Messaging System (SMS), not a lot has happened. The traditional service machinery on the telecom systems has been based on the Intelligent Networks (IN) that origined very much from the operator centric view. In the Internet things have been totally different and the open innovation has always been the top virtue. It is clear that the Telecom world must learn from the Internet and leave the old constraints back to the history. Without the involvement of the community the cell phones will still send SMS messages on the next decade, while the PDAs with the WLAN and direct internet connection are in the cyberspace. A book by Howard Rheingold [22] deals with the topic from various angles.

The openness requires a giant leap from the operator decision makers but it is inevitable, or otherwise the cellular technology will meet the same destiny like the one occurred to the landline phones. The security concerns should not be neglected, and here the operator experience becomes valuable. The Internet deficiencies, such as spam and viruses, must be stopped already before the air interface, and here the Mobile Proxy concept offers a good solution platform. Cellular API specifications must be easy to implement and freely downloadable. Here the Web Services can support the targets.

4.2 Service examples

The important question relates to the services. It is fairly common that a success story from one domain is duplicated and moved to another but that is rarely a good idea [23]. Instead, we should explore totally new and radical P2P ideas that are fully maximizing the potential mobiles can offer. So far the dedicated, cellular based P2P services have not been widely discussed or demonstrated. Most of the services are still running on top of traditional client-server architecture but MP2P could easily improve the end user experience. A couple of ideas have already been presented and they are discussed next.

The proposal of including an application server to the handheld device is not a new one [24]. Lately there has been discussions ongoing whether a Web Server could be installed, not only on the cellular but also on the smart card. A general Web Server and Web Service Interface availability in the portable would enable an easy access to the mobile resources that were described in the previous section. This would surely open totally new possibilities for the service creators, and cellular phones would be close to the full membership of the internet community.

Location aspect can inspire the innovators, too. One example of the location based internet service is called Cell Spotting [25]. Here users try to find new cellular basestations and add attributes based on the cell identifiers. In the hands of the open community, this service will soon create a huge database of the services and attractions located inside the cell. The social relationship can be enforced by combining the physical location with the bluetooth address and the profile information. In the MP2P surrounding the information flow and sharing between the devices would be considerably improved.

Mobile phones are also excellent tools for content sharing. There are already an extensive selection of community sharing services [26], but also a picture sharing [27] suits nicely on the cellular camera usage. At the moment, a user must actively publish the pictures on the Web site but with the concepts described, it could be the picture sharing service provider who pulls the pictures directly from your phone's picture gallery or even further, take live pictures with your camera phone. Another strong evidence of the power of the open innovation is a picture mapping service, see figure 5. This service was built on top of the picture sharing machinery. Both applications benefit from each other, without any license or cross charging needs.

The last example proposes a MP2P search mechanism,

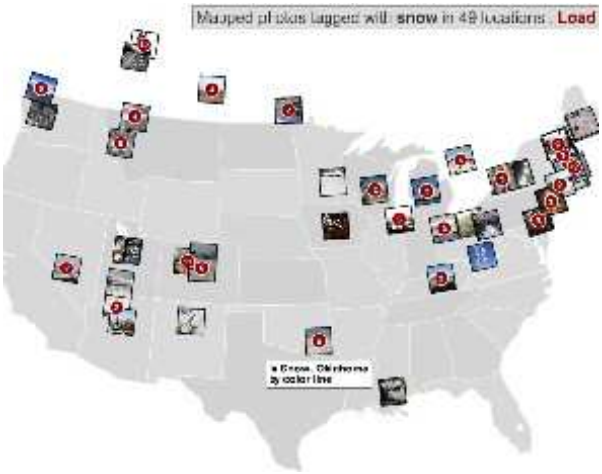

Figure 5: A Picture Mapping Service [28].

utilizing the phonebooks [29]. The idea is based on the real life observation. Normally, humans first try to find the information from the neighboring social network. Within the phonebook this search could be easily extended to friend's friends, etcetera. Contacts provide the seed for the trusted network, and by defining the metadata for the directory listings, a reliable social network could be created.

4.3 Business opportunities

What is the incentive for the cellular operators to join the MP2P world? Today the amount of data traffic and income is still on a very low level, and at the same time, the mobile networks are having a lot of unused data capacity. The increase of the data traffic would not practically create any new costs but just earning possibilities. The basic data charging model can be done with a flat fee a lot simpler than what was the case with the circuit switched speech calls. The setup of the flat fee limits requires a careful planning or otherwise the networks are getting overloaded and furthermore the user experience decreases dramatically. On the other hand, the Mobile Proxy solution would considerably save the air capacity, and even high volume P2P applications could be supported with minimal additional expenses.

The airline mileage gathering systems might show one way to cope with the increased traffic. The static flat fee model is not a good one because the operator looses the chances to earn from the increased traffic and on the hand the end users have to be all the time cautious with the limits and possible extra fees. A considerably high limit is not fair to the low usage customers, either. The answer can be a set of flat fee classes. In the beginning, a suitable traffic class is allocated to each user group, and if the class limit is exceeded or fallen short, the user is respectively uppgraded or downgraded, to the better matching class.

The data traffic charges are probably the most important revenue sources but like already said, the Mobile Proxy solution could also open fully new paradigms. First of all, customers might prefer to pay a monthly fee from the improved content sharing capability and advanced security services to protect the vulnerable handhelds from the risk of the malfunction. Secondly, the Mobile Proxy would enable a broker service where operator could utilize Amazon type of business model by taking the commission of the chargable digital content shared. Advertizing opportunities might also become an attractive additional source of revenue because the mobile user group would be easy to approach.

4.4 End user's standpoint

Consumers would benefit of the cellular MP2P in several ways. The open innovation would explode the application and content offering, and also the end users could have earning chances on their own content. It is clear that mobiles would not be started to use for music sharing cause the same can be done a lot easier with the desktop PC. However, cellular owners would have an incentive to publish, for example, their location information if the outcome would benefit them directly, in the form of better and personalized services. Picture sharing automatically from the phone would be more handy solution than posting them to the separate web sites. Finally, free competion without any operator lock-in would guarantee the economical price level.

5 Conclusions

Mobile Peer-to-Peer is an opportunity for the cellular domain but many challenges need to be first solved. Most of the problems are solvable utilizing the Mobile Proxy architecture but the copyright question seems to be the most ambitious task to be tackled. The solution should be simple, but at the moment the DRM based proposals look often over engineered. It is more probable that the correct answer will be found from a more relaxed copyleft approach, such as Creative Commons. The Web Services Framework supports the Mobile Proxy solution logically and enables a smooth integration of the P2P and Web Services worlds. However, the full utilization requires still a lot more research work.

To get a rich service set, it is an absolute necessity that the open community has free hands to the application development. Operators' role is to provide the secure platforms for the developers and consumers, and that is the way all the players can enjoy the fruits of the new cellular service. Before that is a reality, cellular networks and devices must take giant steps forward but the biggest obstacle is obviously our mindset.

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