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Petros Belimpasakis

Seamless User-Generated Content Sharing in the Extended Home

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To my mother Sofia,
for prioritizing education as one of our top family values

ABSTRACT

User generated content, captured with handheld and mobile devices, is constantly increasing both in terms of quantity and quality, as modern devices have become very affordable and easy to use. At the same time, wide availability of Internet connectivity, either via broadband home PC connections or directly from mobile devices, made it possible to share the captured content with the loved ones, those being family, friends, or even unknown people with common interests.

Based on the human social need for experience sharing, many on-line services, applications and technologies were built to allow photo, video and audio sharing among users of all capabilities. However, this growth of user content sharing has increased the volume of media and diversity of tools, which in turn leads to usability and content repository fragmentation hindrances. Users have their content stored at multiple locations, such as the home, which is the primary place for storing and archiving, online sharing services and mobile devices. Moreover, their sharing habits are usually limited or dictated by the sharing tools and services they use and in many cases they are forced to use multiple solutions for their given use cases.

This thesis studies user-generated content sharing, mainly in the form of snapshot media, in the Internet (i.e. on-line services), mobile and home domains, presenting the main architectures and protocols. Special attention is paid at the home domain as the networked home is expected to play an important role in the years to come, by considering spatial and functional extensions, leading to what is called ”Extended Home”. This could enable new ways of content sharing, without the need of uploading the content to 3rd party services and sites. Thus, emphasis is put on the concept of ”remote access” to home networks, which is a key enabler. The author suggests that content sharing can be abstracted so that devices and applications could function independently of the actual protocols and bearers used, introducing the concept of seamless content sharing.

Seamless content sharing encompasses the abstraction of different content repositories and sharing methods, such as sharing directly from the home, via on-line services, or with devices in proximity, so that the user does not need to deal with technical details, access bearers or sharing protocol selection. Rather, users should be able, in a ”user-centric” manner to just select the person that they want to share content with and let the system automatically choose the best possible method and technology, in a transparent manner. Moreover, the author presents novel architectures for content sharing in nomadic and extended home environments, even going beyond sharing of multimedia content, towards any kind of user-generated content to not only users but also external, semi-trusted, services.

PREFACE

The work presented in this thesis has been carried out at Nokia Research Center, Finland, within the scope of the many home related projects and teams I have been working in, mainly during the period 2005-2008. The work would not be possible without the help and support of many people, who I would like to acknowledge.

First of all I would like to thank my university supervisor professor Jarmo Harju, for guiding me in the academic path of this research and always being available for reviewing and providing constructive feedback on the executed work. I would also like to thank the examiners of the thesis, professor Frank Reichert and professor Antti Ylä-Jääski, for their careful reading and feedback on the thesis manuscript.

From Nokia Research Center, I would foremost like to thank Seamus Moloney and Rod Walsh, who have been the leaders of the ”Extended Home” and ”Home Solutions” teams, in which I belonged while this work was carried out. They both provided me with a unique and flexible environment that allowed my university studies execution in parallel to my full time job. Moreover, I would like to thank Harri Hakulinen, as the program manager of the ”Digital Living” program, who trusted and delegated to me the leadership of the ”Content Sharing” work package, under which most of my work was executed. I also owe special acknowledgment to Dr. Mika Grundström, my first team leader at Nokia, for providing me the opportunity to join his team and introducing me to the digital home domain, as well as being a constant coach through my career.

As most of this thesis work has been carried out in the context of wider, multi-people, programs and collaborations I would also like to thank all my co-workers who contributed in making the working environment engaging and enjoyable, especially my publication co-authors. The preparation of this thesis was financially supported by the Nokia Foundation, which I would like to thank for providing me with the respective grant.

I would like to thank all my friends, both in Finland and in Greece, for their joyfulness and quality time spending, which created the perfect work, study and life balance. Especially Danai who has been an excellent friend, university classmate and a great listener over daily coffee breaks.

This work would not have been possible without the moral support of my mother Sofia, brother George and his wife Nagihan, as well as my family in Crete. Despite our geographical distance, they were always there for me to support and advice, through their valuable experiences. Finally, I am most grateful to my life companion Anna, for being next to me during the cold Finnish winters, long studying days and nights. Her continuous support, understanding and sacrifices have been encouraging me to reach my goals throughout this highly demanding period.

Tampere, May 2009

Petros Belimpasakis

TABLE OF CONTENTS

LIST OF PUBLICATIONS

This dissertation consists of a summary and eight publications. The publications are referred to in the text using their Roman numerals I-VIII.

[I] P. Belimpasakis, A. Saaranen and R. Walsh, "Home DNS: Experiences with Seamless Remote Access to Home Services" in *Proceedings of the Eighth IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2007)*, Helsinki, Finland, June 2007.

[II] P. Belimpasakis, V. Stirbu, "Remote Access to Universal Plug and Play (UPnP) Devices Utilizing the Atom Publishing Protocol" in *Proceedings of the Third International Conference on Networking and Services (ICNS 2007)*, Athens, Greece, June 2007.

[III] P. Belimpasakis, J-P. Luoma, M. Borzsei, "Content Sharing Middleware for Mobile Devices" in *Proceedings of the First International Conference on Mobile Wireless Middleware, Operating Systems, and Applications (MOBILWARE 2008)*, Innsbruck, Austria, February 2008.

[IV] P. Belimpasakis, S. Moloney, V. Stirbu, J. Costa-Requena, "Home media atomizer: remote sharing of home content - without semi-trusted proxies" in *IEEE Transactions on Consumer Electronics*, vol.54, no.3, pp.1114-1122, August 2008.

[V] P. Belimpasakis, R. Walsh, "A Resource-efficient Mobile Blogging System" in *Proceedings of the Sixth International Workshop on Applications and Services in Wireless Networks (ASWN 2006)*, Berlin, Germany, May 2006.

[VI] P. Belimpasakis, S. A. Awan, E. Berki, "Mobile Content Sharing Utilizing the Home Infrastructure" in *Proceedings of the Second IEEE Conference* *and Exhibition on Next Generation Mobile Applications, Services and Technologies (NGMAST 2008)*, Cardiff, Wales, UK, September 2008.

[VII] P. Belimpasakis, A. Saaranen, "Seamless User-Oriented Content Sharing". *Tampere University of Technology. Department of Communications Engineering*. Research Report 2009:1, 23 p., Tampere 2009.

[VIII] P. Belimpasakis, M-P. Michael, S. Moloney, "The Home as a Content Provider for Mash-ups with External Services" in *Proceedings of the Sixth IEEE Consumer Communications and Networking Conference (CCNC 2009)*, Las Vegas, Nevada, USA, January 2009.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

3G	3rd Generation
ADSL	Asymmetric Digital Subscriber Line
ALG	Application Layer Gateway
API	Application Programming Interface
AV	Audio/Video
BT	Bluetooth
CD	Compact Disc
CDS	Content Directory Service
CRUD	Create, Read, Update, Delete
DCMI	Dublin Core Metadata Initiative
DHCP	Dynamic Host Configuration Protocol
DLNA	Digital Living Network Alliance
DNS	Domain Name Service
DVD	Digital Versatile Disc
FP	Feature Pack
FTP	File Transfer Protocol
GB	Gigabyte
GOEP	Generic Object Exchange Profile

GPS	Global Positioning System
HTML	HyperText Markup Language
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IGD	Internet Gateway Device
IMAP	Internet Message Access Protocol
IM	Instant Messaging
IMS	IP Multimedia Subsystem
IP	Internet Protocol
IPSec	Internet Protocol Security
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
ISP	Internet Service Provider
IT	Information Technology
LAN	Local Area Network
MMS	Multimedia Messaging Service
MSISDN	Mobile Station International ISDN Number
NAS	Network Attached Storage
NAT	Network Address Translation
OBEX	Object Exchange
P2P	Peer-to-Peer

PC	Personal Computer
PDA	Personal Digital Assistance
POP	Post Office Protocol
REST	Representational State Transfer
RSS	Really Simple Syndication
RTP	Real-time Transport Protocol
SIP	Session Initiation Protocol
SMS	Short Messaging Service
SMTP	Simple Mail Transfer Protocol
SOAP	Simple Object Access Protocol
SSID	Service Set Identifier
STUN	Session Traversal Utilities for NAT
TB	Terabyte
TCP	Transmission Control Protocol
TLS	Transport Layer Security
TTL	Time to live
UDA	Universal Plug-and-Play (UPnP) Device Architecture
UDP	User Datagram Protocol
UGC	User-Generated Content
UI	User Interface
UPnP	Universal Plug-and-Play
URI	Uniform Resource Identifier
URL	Uniform Resource Locator

VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
WAN	Wide Area Network
WAP	Wireless Application Protocol
WebDAV	Web-based Distributed Authoring and Versioning
WEP	Wired Equivalent Privacy
Wi-Fi	Wireless Fidelity
WiMAX	World Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WPA	Wi-Fi Protected Access
WPAN	Wireless Personal Area Network
WWW	World Wide Web
XML	Extensible Markup Language

1. INTRODUCTION

In this first chapter, we introduce the objective and scope of the research carried in the context of this thesis, followed by the main contributions and an outline of the subsequent chapters.

1.1 Positioning Seamless Content Sharing

Aristotle stated that man is by nature a social animal [96], while many centuries later Maslow classified the social needs in the middle of his famous hierarchy of needs pyramid model [72]. After satisfying their physiological and safety needs, humans have the social needs of friendship, intimacy and communication.

The means of communication has significantly changed during the last years, starting with the invention of the telegraph, followed by the fixed/mobile telephone and radically disrupted with the wide adoption of the Internet. While people would originally communicate via voice or limited text, new technologies have added a lot of new dimensions, allowing not only to have verbal discussions, but rather exchange messages, images, videos and generally experiences.

As digital cameras became common place, average consumers were able to generate their own content, directly in digital format, and transfer it to their personal computers for further processing, such as archiving, printing or sharing. But, it was mobile phones with built-in cameras that brought the content creation devices to the masses. Around this ecosystem, new content distribution channels became available, with dedicated on-line services, facilitating content storage and sharing, among family, friends and the wider community in general.

The next disruption is expected to happen in the home domain, as residential broadband connections have become a reality for many. The single home computer for accessing the Internet has been replaced with home networks containing many interconnected multimedia devices, at least in the well developed countries, which promise to make communication even richer. Trends show that between 2005 and 2010 personal non-commercial storage content in a typical digital home could increase from about 323 Gigabytes (GB) to almost 2 Terabytes (TB), while cumulative commercial content in the same digital home could grow to almost 2.5 TB [23]. Fig. 1 presents the estimated cumulative growth of personal and commercial content in a digital home from 2005 through 2010.

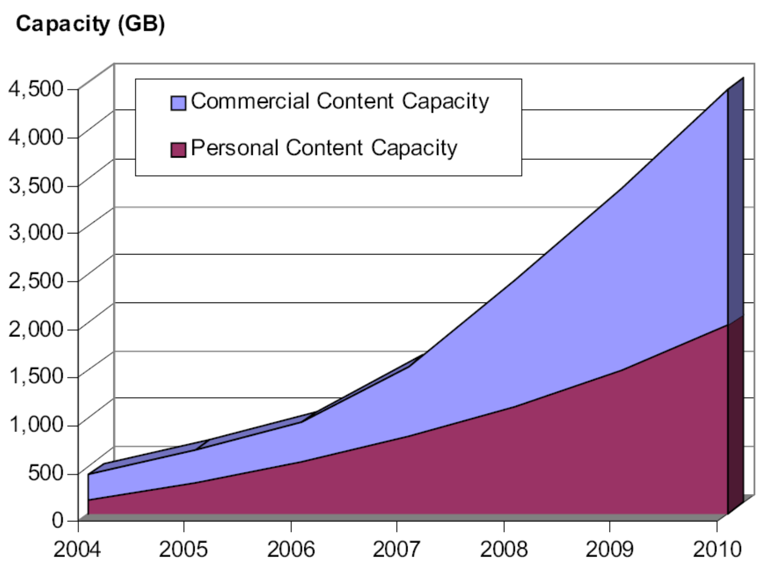

Fig. 1. *Estimated growth in cumulative home personal and commercial content storage capacity [23]*

All these advanced developments, in the previously mentioned domains of *content*, *on-line services*, *mobile* and *home*, create new space for innovative applications and services. But, those domains are not isolated silos, rather there are crossover areas, which give birth to new areas of research. The author has identified the following research sub-domains, as a result of the main domain overlapping:

- **Remote Access** to home networks addresses the remote accessing of home resources, from mobile, or other external devices, thus combing the home and mobile domains. This area is directly addressed by [I] and [II]. The term Remote Access is widely encompassing the notion of remote device & appliance control, remote surveillance and remote media access.

- **Mobile Internet**, is the area where on-line Internet services and mobile domain converge, such the work of [III] and [V]. This area typically includes research on services optimized for mobile usage, bridging the fixed networks with mobile ones and all types of wireless network access.

- **Content Distribution** research studies how large amounts of content can be indexed, searched and effectively distributed over the Internet, essentially combining elements from the content and on-line services domains. This area encompasses content delivery networks, peer-to-peer media exchange and content streaming.

- **Content Storage, Archiving and Consumption** of multimedia content at home, allows the homes to evolve into powerful entertainment centers. This area of research is a combination of the home and the content domains, covering aspects of pervasive computing, service and content discovery and in-home media sharing.

At the same time, in some areas there is crossing of more than two domains. More specifically:

- The intersection of on-line and mobile domains, in relation to content, leads to different aspects of content distribution, streaming and sharing. In the context of this thesis, focus is put in *Content Sharing*, which refers to sharing of digital media, between user devices (mobile or fixed), usually via an on-line service. This widely used term can be considered broad enough to encompass any kind of content and media exchange, either in the mobile or on-line domains.

- The cross-over of the home, mobile and content leads to the notion of the *Extended Home*. It refers to the concept that ”distributes” the resources of a traditional home network over multiple (physically) separated domains, while enabling the user to have similar usage experiences as if accessing the services directly from his primary home [89]. This is the de facto term used in relevant research, such as in [3], [63], [13], [89] and [90].

Placing these domains on a common plane, the author suggests that there are overlaps and convergence areas, as illustrated in Fig. 2.

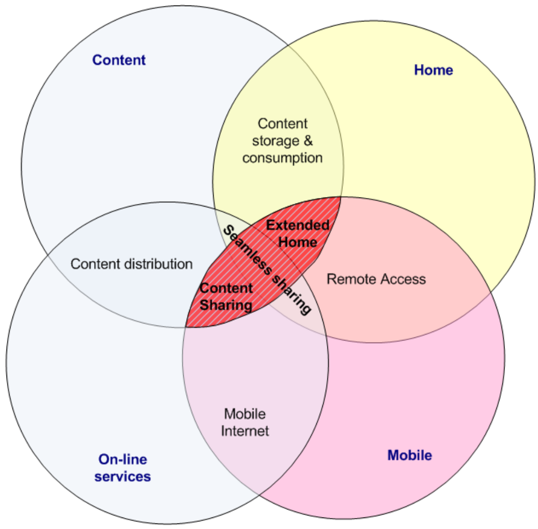

Fig. 2. *Positioning seamless content sharing*

The convergence of the *Content Sharing* and the *Extended Home* areas, is what the author calls *Seamless Content Sharing* [VII]. Seamless Content Sharing is a concept that would allow users to share their content, which might be distributed in multiple locations, in a transparent and uniform way. In this concept, the home is expected to play an important role in many ways. For example, the home could host and offer content to remote users [IV], or it could become the hub for group based content sharing [VI] and open up its infrastructure to external services, for rich mash-ups [VIII].

1.2 Research Question

The main research question of this dissertation is: can the user-generated content be seamlessly shared, no matter its physical location, among family and friends? This leads to other sub-questions, such as: how do home, Internet and mobile domains converge when it comes to content sharing and what is the common denominator of different content sharing protocols of the mentioned domains? Finally, how could existing sharing solutions be enhanced to make the process simpler and more social?

1.3 Objective and Scope of Research

The objective of this research work is to study the content sharing solutions, both on the Internet/mobile world, as well as the extended home, leading to unified content sharing architectures. The target is to show that there are many commonalities but still that those complement each other, in such a way that we cannot say that either sharing directly from home or sharing utilizing on-line Internet services is better, in an explicit manner. We want to show that each of the different methods has its advantages and disadvantages and users will always have content stored at multiple locations, depending on the context of usage. Moreover, we want to prove that utilizing existing protocols, with relatively small functionality extensions to mobile and home devices, content sharing methods can become seamless, hiding the distinctive characteristics of each from the users. For this, many prototypes were built, tested in laboratory environment and our core concept was even validated by real users, via a usability trial.

The scope of this research work is sharing of user-generated media, mainly focusing on snapshot media (such as photos and video clips) and leaving outside of our scope the streaming media. As, nowadays, mobile camera phones play an important role in the creation of such media, we assume that they are the main capturing devices but also one of the main tools for initiating a content sharing transaction. Moreover, the Extended Home is the other area of focusing our work, assuming that broadband digital home networks will be a reality for many families in the near future. In this context, issues related to content sharing within the home domain, including remote access methods and techniques are of our core interest.

This work is mainly driven by the engineering challenges and research opportunities in the networking and communication protocols areas, even though it also touches other disciplines and domains, such as multimedia, social networking and usability. However, it should be mainly considered as engineering research, targeting people with information technology and computer science backgrounds.

Finally, related to the actual technologies involved, our focus is on protocols that can be widely used on the existing Internet and are already available for most existing home users. As such, our studies and solutions are mainly based on sharing solutions that are Internet Protocol (IP) based and more specifically compatible with IPv4, since it is still the dominant protocol on host home Internet connections. Thus, IPv6 which solves many of the challenges but is still not a reality for most users, is not considered as the prime candidate for our solutions.

1.4 Methodology

Järvinen [58] proposes a taxonomy of research methods, as shown in Fig. 3, where IT research can be classified as "Approaches studying reality".

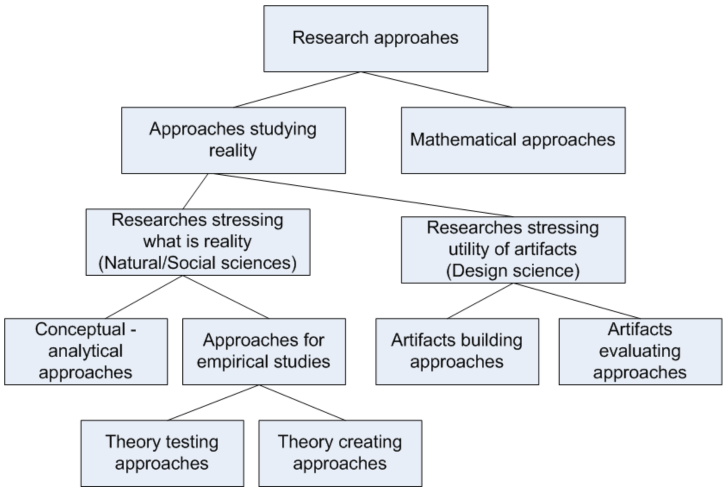

Fig. 3. *Taxonomy of different research methods*

Then, further categorized, methods are split into "Researches stressing what is reality" (trying to answer "how and why things are") and "Researches stressing utility of artifacts" (focusing on utility innovation). March & Smith [71] argue that Information Technology (IT) research studies artificial as opposed to natural phenomena. It deals with human creations, such as information systems. While natural science tries to understand reality, design science (which is technology oriented) attempts to create things that serve human purposes.

The research work of this dissertation has been following the "Design science" approach, building solutions, enhancements and innovations that deliver value to the humans and service their purposes. Some of the work has been suggesting concept solutions and designs, such as in [II] and [V]. But, most of the executed work has been both building and technically evaluating artifacts (prototypes) of Information Systems, such as in cases of [I], [III], [IV], [VI], [VII] and [VIII].

Moreover, the publication [VII] included a usability study which is classified under the ”Natural/social science” methodology and more specifically it was an empirical approach study for theory testing. We used a qualitative sessions for gathering insight and testing our assumptions. From the Interaction Design point of view, we used the following two research methods, for this study:

- Usability testing [101], during which the users were given specific tasks to solve on their own.
- Paper prototyping, according to the low-fidelity prototyping method [102].

1.5 Contributions of Research

The research contribution of this work has four parts, as it touches on a few areas of user-generated content sharing and the home domain. Firstly, studying home networks we identify the challenges for sharing content directly from a home, that is without the need to upload it to an on-line service and propose solutions that solve some of these issues, mainly in publications [I], [II] and [IV]. This work contributes directly towards the ”Remote Access” to home architectures, so that remote home access becomes easier and more transparent to the users.

Secondly, we establish the commonalities between the sharing protocols widely used in the home, Internet and mobile domain and propose sharing solutions that link the mobile sharing closely to the digital home domain, in publications [III] and [V]. The novel aspects of the work include the abstraction of different sharing protocols and suggesting how the home infrastructure could be used to make mobile content sharing more resource-efficient.

Thirdly, putting all studied elements in a common framework we suggest that content sharing can become ”user-centric”, so that people share media with other people, without the need to know and care about the bearers, protocols and technologies used, mainly in publications [VI] and [VII]. We basically shift the starting point of content sharing towards people, emphasizing the importance of social networking rather than the actual technologies. Without changing the underlying technologies, wrapping architectures are suggested for archiving this goal.

Finally, we also briefly study how content sharing can go beyond sharing with family and friends, to sharing with external services, so that home hosted content can be mashed-up with 3^{rd} party services, in publication [VIII]. Our work suggests how the home infrastructure can be opened towards other services, in a modern web mash-up architecture, while preserving the security and privacy aspects of home networks. This pushes the boundaries of user-generated content sharing even further, beyond snapshot media (e.g. considering shopping lists and calendars as user-generated content), providing future research directions where the digital home would be the hub of everyday family activities.

1.6 Thesis Outline

In the next chapters first the user-generated content and general sharing concepts are introduced, followed by a presentation of content sharing methods at the on-line and mobile domain, their characteristics and challenges. Then, home networks and content sharing in the extended home domain are studied, followed by a chapter dedicated to seamless content sharing. Finally, conclusions and future research directions are given.

2. USER-GENERATED CONTENT

2.1 User-Generated Content Life Cycle

Digital multimedia content usually refers to digital images, videos and audio that can be stored in a computer system, transfered and reproduced (rendered) by a compatible device. Until recently, the content life-cycle was starting by the production, handled by a small number of professionals and ending with its consumption by a large number of end-users. This was the typical model, applied in cinema, television, radio and, of course, the Internet, where the end-users were just passive consumers of the content. However, recently this content life-cycle has been disrupted, with the end-users also becoming content creators and distributors, of what is called user-generated content (UGC). The typical consumer generated content life cycle, based on the video work analysis of Kirk et al. [62], is shown in Fig. 4.

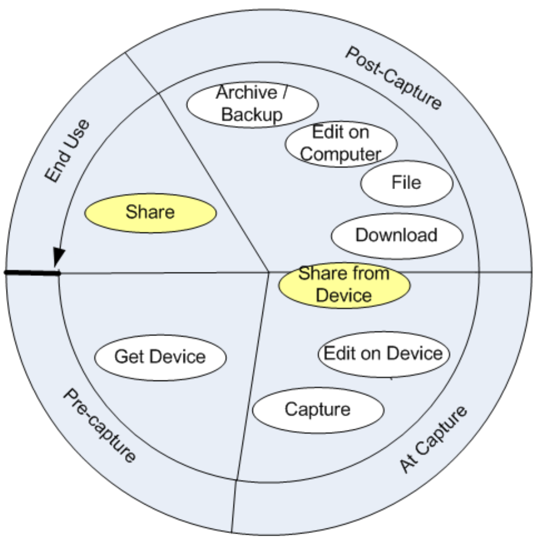

Fig. 4. *User-generated content life cycle*

Briefly, we can describe the main four phases as:

- Pre-capture: The action of acquiring a capturing device. Consumers are lead to the identification of the value of a capturing device usually via the importance of an event that they would like to have recorded.
- At-Capture: Capturing of digital image/audio/video content. Also, many users consider sharing the content, directly from their device, at the "at capture" stage. Theoretically, also editing is possible at this phase, but rarely done.
- Post-Capture: The process of downloading the content to a personal computer and file it for further usage. Editing of the content, on the PC, may also happen depending on the usage intentions.
- End-Use: Sharing the completed (raw or edited) footage, via various methods, such as sending over e-mail, uploading it to an Internet site, or simply burning on a DVD and giving it.

The focus of this thesis is the *Sharing*, both "At-Capture" (i.e. at the capturing device) and at "End-Use" (i.e. after downloaded to the PC).

Content is now created, in a large extend, by non-professional users who create and share UGC to small communities and groups [82], and this shift is also refereed to as "Long Tail" [3], as shown in Fig. 5.

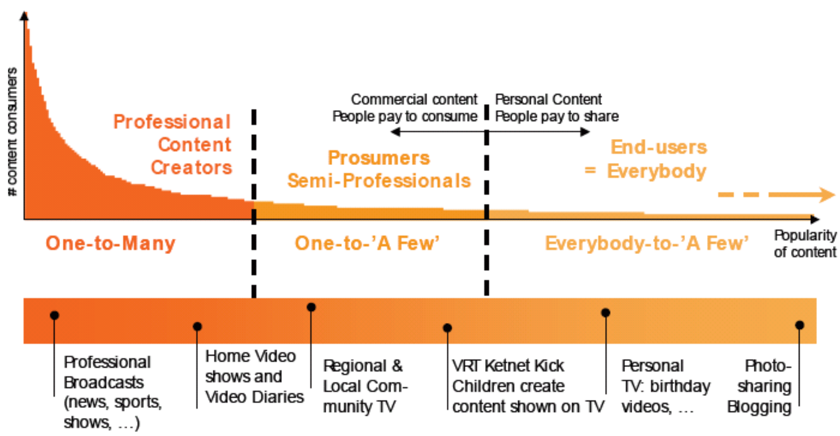

Fig. 5. Long Tail content creation [3]

The non-professional users [80] evolve from being just passive consumers of media content to becoming producers, distributors and thus being an active part of the media value chain [82]. Improved ease of creation, storage and usage tools are the main reasons of this, as well as the increasing presence of digital creation and authoring tools away from the desktop.

However, it is still a reality that ”...far more amateur video is shot than watched...” [26], meaning that there is still a lot of potential for making content sharing easier and more intuitive, which is exactly what this thesis is targeting.

2.2 Content Creation

Hand-held devices made it possible to capture content at any place, when something interesting would appear or occur. As digital cameras stopped being only professional tools, but also entered the consumer electronics market they attracted the early adopters into the digital content creation world. However, it was camera phones that made content creation a reality for many more.

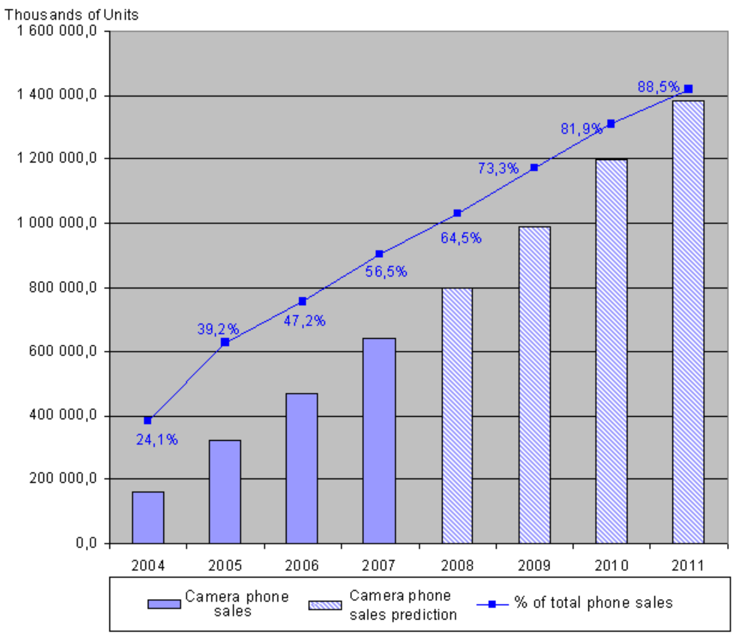

Fig. 6. *Worldwide camera phone sales*

The simplicity of carrying only one device with multiple functionality, as well as the continuously decreasing prices made the camera functionality almost a ”standard” feature of most advanced phones. Global sales of camera phones surpassed

640 million units, in 2007, up from nearly 468 million in 2006. Camera phones will account for nearly 89% of the mobile phones sold in 2011, reaching about 1.4 billion units [77], as shown in Fig. 6. To compare these numbers with the sales of digital still cameras, market reports estimate that camera phone sales have increasingly outstripped digital still camera sales, by a ratio of 4:1 in 2004 and an expected ratio of 7:1 by 2010 [10].

The mobile domain plays an important role in the UGC creation, as a large portion of the world's population will have a camera phone, in the years to come. Moreover, as we will see also in the chapters to come, camera phones do not act only as capturing devices, but with their advanced network connectivity systems they can offer content related services at any place, any time.

As modern consumer-oriented media creation devices can nowadays also capture video, other forms of media are being used in a similar way to the use of photographs. All these forms of media is bundled under the term snapshot media [97] which includes video clips, text messages, multimedia shows, and so on, which are created by non-professionals for non-commercial purposes and the intended audience is themselves and their social network (i.e., family, friends, etc.). In the context of this thesis user generated content mainly refers to all snapshot media, but photographs are used as the primary example, in most of our scenarios.

2.3 Content Sharing

Digital content creation, apart from being an enabler to keep memories, it has one even more important function. By sharing it, people use photos, and other media, to convey complex thoughts, feelings, or portrayals of their identity to others [12]. Sharing content, between different groups of friends, allows people to stay in touch, broadcast their social presence and exchange experiences with their loved ones. The authors of [65] suggest that mobile multimedia mainly supports mundane interaction, meaning that it is used in many scenarios, such as gossiping and keeping in touch with friends and family [68].

To define *sharing*, one could say that it means the possibility to show, send, give or offer items in a (reciprocal) condition between at least two people [57].

Getting into more detail, we will be looking into three important social and technical aspects of sharing:

- *Sharing paradigms*, or elementary use cases, that users subject their content to.
- *User groups* that sharing implicates.
- The concept of *social media*, that extends the typical content.

These concepts help us build the core elements of content sharing solutions, that will be analyzed in this thesis.

2.3.1 Sharing Paradigms

There are four main paradigms of sharing content [10]:

Showing: ”Showing” is to display content items face-to-face, or remotely, without transferring the items out of the device, but directly rendering the content on it. An example of face-to-face showing would be the scenario were people would view content items (such as images or videos) on a device controlled by the owner. That could be a mobile phone, television screen or PC. In the remote context, the content receiver is not visible out of one’s eyesight. An example scenario would be the usage of service that supports the ”see-what-I-see” paradigm, such as mobile 3G video call or PC desktop sharing application. Showing content requires person-to-person real-time interaction, so it is mostly used for sessions among family and friends, where the participating users know each other.

Sending: In the ”Sending” paradigm, the content items to be shared are transferred remotely to one of the recipient’s devices. That could be either the original media file or a copy of it. Examples are the very common e-mails, which include media items as attachments, or sending content using the Multimedia Messaging Service (MMS) message between two mobile phones. People are very familiar with the sending paradigm, mainly as Internet e-mail has been the dominant method of digital content sharing for many years. As in the previous case, sending is also mainly used for person-to-person communication as, usually, previous knowledge of the recipient is required, before sending any content.

Giving: ”Giving” refers to the physical or face-to-face hand over of media items. The transfer could include the original media items or copies of them are transferred from the sender's to the recipient's device. It mainly applies to wireless proximity based sharing, where a near-field communication technology (such as Bluetooth [14]) is used for transferring digital content between devices in physical proximity. Giving physical media, such as handing over some CD or DVD to another person, follows this paradigm as well. The face-to-face aspect of this method sets a basic requirement on the interaction of people in proximity, that most probably know each other, and thus there is usually a relation of trust between the participating users.

Offering: "Offering" means to make content items available remotely or face-to-face, for others. Items are not transferred unless requested by the other party and only a copy can be taken (not the original item). Examples include offering of images and videos on a typical Internet website, or offering music files via peer-to-peer networks, in the remote case. The hosting service can be on a personal, or 3rd party server, while in the face-to-face case content is directly offered from one of the owner's personal devices, in proximity. Such an example, of proximity based content offering application, is the Nokia Sensor [88] application. The actions of offering, by the owner, and downloading by the recipient, are asynchronous and require no personal pre-knowledge or social link of the two parties.

2.3.2 User-Groups

One of the first studies focusing on consumer photography was the [19] where the author introduced the concepts of home mode and Kodak Culture. The "home mode" communication showed that consumers typically share photos and video footage of traditional events such as birthdays and family holidays. The author introduced the term "Kodak Culture" for the participants of this "home mode", where were typically family members and friends, i.e. people that know the persons captured in the images. But, in the digital era where media sharing is possible via many different ways, the groups of people that content can be shared with has become wider.

When sharing digital content, the paradigms described before need to be applied depending on the context of usage and the people that the content would be shared with. Typically, the content owner would grand some access rights to other users, in order to allow them to access and retrieve the content. Depending on the real life relation that the content owner has with the potential recipient, we can identify four classes of users [10], as also shown in Fig. 7.

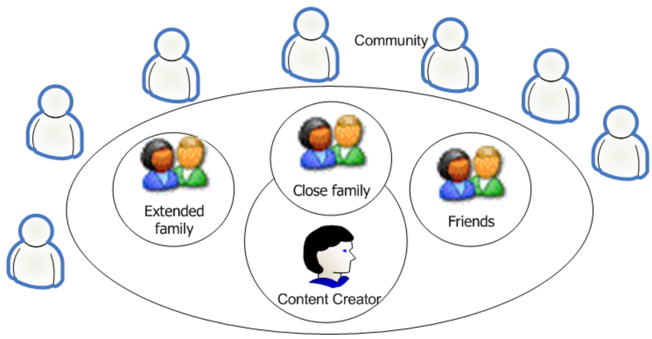

Fig. 7. Classes of users, related to user-generated content sharing

In more detail, those groups of users are:

Creator is the owner of the content and typically full has access rights to it, meaning that he can read, edit, print and delete it. Is also the main person to decide who can access it and how, i.e. using which sharing paradigm and technology.

Close family members are the very close members of creator's family. Those are usually people who live in the same physical home, as the content creator. Typically, those people have full access rights to most of the content and they are allowed to also add their own content in common media repositories. For example, family members can be adding all their content of a vacation trip in the same photo album.

Extended family and friends are people socially linked to the content creator. Typically they do not live in the same home as the creator, but they would be welcome to physically visit. This means that there is a trust relationship between these people and the content creator. Based on this trust, those people would be typically allowed to access content, with read access rights to specific media albums and maybe granted the right to add content in albums that were created for common experiences and events, if the sharing platform used would support this functionality.

Community is a much wider group of people who share some common interests with the content creator, but are not typically known to him. An example would be a group of people with the same hobbies that would like to exchange related images and videos of their activities and experiences. Since there is no direct relation with these people, they would not be trusted with very personal content. Thus, these people would typically have only read access rights to very specific content albums. Sharing content on public photo sites would be a common scenario for this class of users.

2.3.3 Social Media

In the context of sharing content to the community, many on-line services - called social media sites - have been focusing on sharing user generated content, in a social manner. Social media typically includes a much richer variety of information sources: in addition to the actual content itself (such as an image), there is a plethora of extra non-content information mapped to the content, such as links between media items, quality ratings from members of the community [4], short tags describing the content and very often free text comments by the viewers. Fig. 8 illustrates the basic concept of social media.

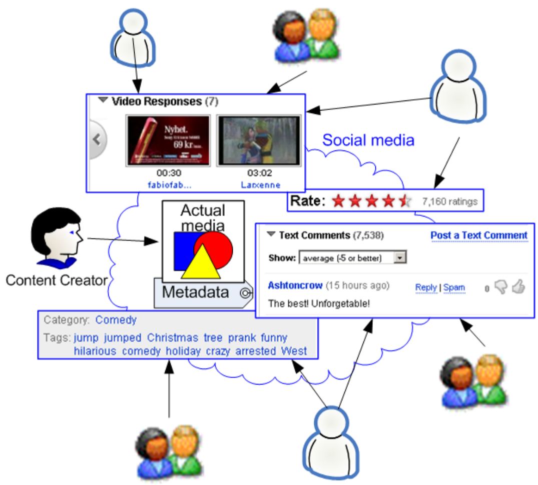

Fig. 8. *Social media*

Popular social media based services include blogs, web discussion forums, photo and video sharing communities. Probably, the most interesting ones are the, nowadays, widely used social networking platforms such as Facebook[1] and MySpace[2]. Social networking services offer a combination of sharing, discussing, personalizing functionality but they heavily emphasize the relationships and social links among the participants of the community. Due to their general simplicity and easiness of creating social media, social networking sites have become extremely popular. According to latest statistics [36], in November 2008, Facebook alone had more than 110 million active users, with a total of 10 billion photos uploaded to the site, while having 30

[1] Facebook: http://www.facebook.com/
[2] MySpace: http://www.myspace.com/

million photos uploaded daily. Moreover, Facebook is the 4^{th} most-trafficked website in the world.

2.4 Metadata

Metadata was first introduced in library systems [106], to help searching a book in a library. Library cards describing the key attributes of a book (such as authors, title, year, location of the book in the library) are used to make search easier, than going around the library looking through out all the books.

Metadata is ”data about data”, which in the scope of information technology means digital information that describes a set of digital data, such as a digital object [97]. Typically, digital media (e.g. a photo) is linked to some metadata describing the media, such as title, creator, subject, date. Moreover, as digital media is in the form of a digital computer file, there is also metadata describing the actual file (e.g file size, date/time of creation and last modification). One of the widely used standards for media object metadata is the Dublin Core Metadata Element Set [28].

In the context of user-generated content, metadata is the key into helping people organizing the media files into albums and archives, for further reference as well as helping others search for the content that they are looking, on an on-line sharing site for example. But, manually adding metadata to personal media is not a realistic scenario, as it requires intensive user activity (e.g. writing the location of capturing at every singe media item on the user’s media collection). This is why devices have been getting ”smarter” in automatically adding metadata to the captured media, while in the ”At-Capture” phase. Digital cameras have been always adding the date/time of capturing, as metadata to their produced content. Modern mobile phones support ”geo-tagging”, which allows them to also add the exact location of capturing, utilizing live data from the Global Positioning System (GPS) receiver or a list of people around, using Bluetooth-sensed co-presence [27].

2.5 Summary

In this chapter a holistic view to user-generated content was provided. The typical content life-cycle was presented, followed by more insight in content creation and the important role that mobile phones have played, for making digital media capturing available to the masses. Content sharing, which is the main focus of this thesis, was presented and the four sharing paradigms (Showing, Sending, Giving, Offering) where explained, followed by the different groups of people, potentially, involved in a sharing transaction. Finally, the concepts of social media and metadata were presented, as they are closely linked with user generated content, when it comes to sharing and organizing.

3. CONTENT SHARING IN THE INTERNET AND MOBILE DOMAINS

The primary domains of digital content sharing have been the Internet (i.e. on-line services) and the mobile domain. In this chapter, we will present their existing sharing solutions and protocols, as well as the main limitations and challenges.

3.1 Background

Sharing digital content on the Internet has been possible as early as the days of e-mail and the File Transfer Protocol (FTP) services. But, those services were mainly focused on just exchanging computer files, any kind of files, rather than been optimized for multimedia content. The concept of content management [15] was totally missing, meaning that these services did not support the evolutionary life cycle of the content. As we will see in the next section, many new sharing solutions were developed for providing richer sharing experience on the Internet.

Moreover, a few years ago, we would say that the ”Internet” and the ”mobile Internet” where almost two separate worlds, interconnected via proxies and bridges. Specific mobile-only technologies, such as the Wireless Application Protocol (WAP) for mobile web browsing, and Multimedia Messaging Service (MMS), for media sharing, were developed. Reason was that mobile devices were very much resource constrained, having small screens, narrow bandwidth data links, limited processing power and memory. However, nowadays mobile devices have powerful processors, large displays and multiple high-speed connectivity bearers matching, or even exceeding the fixed-Internet end-user speeds. Mobile devices now have the capabilities of being fully qualified Internet nodes, able to perform actions and render content as well as the desktop computers. Thus, many of the Internet protocols can be directly used on the mobile-Internet domain, but unfortunately the same does not apply to user interfaces, as the context of usage of mobile devices is different than the usage of a desktop PC. In this thesis we study the mobile Internet in the same manner as with the fixed Internet, in terms of protocols and technologies, especially since in relation to content sharing the only constraint of the mobile Internet is energy and power consumption. But, in terms of usability and user experience, we still keep the fixed/mobile separation.

3.2 Content Sharing Solutions

3.2.1 Messaging Services

Messaging services on the Internet allow users to exchange electronic messages, with leading example being the Internet e-mail. Messages can include attachments of any kind of file, thus it is also possible to carry multimedia content. As shown in Fig. 9, the sending node forwards the message to a messaging server, using for example the Simple Mail Transfer Protocol (SMTP) [64], which is one of the most widely used protocols, for sending e-mails. The headers of the message include the address of the recipient, being in the well know *user@domain* format and the payload includes text along with attached files. The recipient can retrieve e-mail messages from the messaging server, utilizing protocols such as the Post Office Protocol (POP) [75] and the Internet Message Access Protocol (IMAP) [25], in a message-pull fashion.

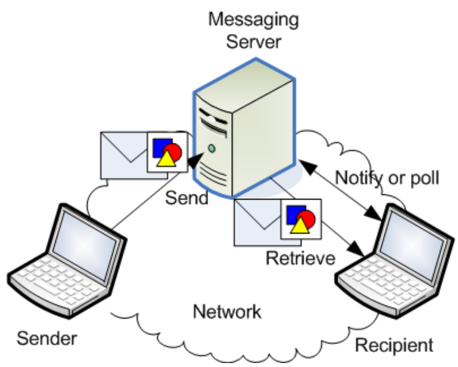

Fig. 9. *Model architecture of messaging services*

E-mail protocols can be directly usable on the mobile domain and most mobile phones have a build-in e-mail client, however, the restricted user interface might require a lot of user actions, before the average user is able to share content. Solutions like [69] try to make content sharing, over mobile e-mail, easier. But, to optimize even more the experience of mobile content sharing, the cellular telephone industry has also defined a service known as the Multimedia Messaging Service (MMS) [2]. The core of the service uses formats and protocols that are similar to, but differ in many ways from, those used in Internet e-mail [42]. However, the important aspect is that MMS is also message oriented, supporting file attachments and addressing recipients in a similar to e-mail address scheme. In MMS, addressing recipients can be done either using the e-mail-like *user@domain* format, or using the Mobile Station International ISDN Number (MSISDN), which is the mobile phone number of the recipient user.

Moreover, nowadays instant messaging (IM) services allow users to quickly exchange short messages, in a chatting-like fashion and near real-time manner. These services are based on an emerging number of standard protocols (SIP/SIMPLE, Wireless Village, JABBER, etc.) in addition to proprietary protocols (MSN, Yahoo!, AOL, etc.) and standard APIs (JAIN SIMPLE, JAIN Presence, JAIN Instant Messaging, PAM, JAIN PAM, etc.) [29]. Clients for many of these protocols exist also for mobile devices, even though dedicated IM services also exist, and being natively supported by the IP Multimedia Subsystem (IMS) [1,43] of the cellular networks. As in e-mail and MMS, instant messages can also carry attachments, combined with text.

In relation to UGC, messaging services are very efficient and simple to use, since they follow the user-centric paradigm, meaning that the sender selects the content he would like to share and addresses it to a specific person. The recipient address of an e-mail or an MMS is typically mapped to a physical person. Even more, people are already well aware of the attachment paradigm, from the long usage of Internet e-mail and attaching media items to messages is usually a straight forward procedure for them. However, there are some key limitations, the most important one being the size of attachments that can be accepted. In typical Internet e-mail, attachments cannot exceed a few megabytes of size, while in MMS the limit is even lower, due to the limited capabilities of devices. Thus, the users cannot send large number of high quality images over e-mail or MMS, which renders these services not very practical in real life, especially as the content quality and size keeps increasing.

Based on our classification of sharing paradigms, as presented in section 2.3.1, messaging services are following the *sending* paradigm.

3.2.2 On-line Content Hosting/Sharing Services

On-line content hosting and sharing services are typically web sites that allow the users to have their multimedia content uploaded to a their servers, along with different types of metadata, such as description, textual tags describing the content and geographical location of the capturing location. The content uploaded to the on-line services is typically linked to a Uniform Resource Locator (URL), based on which other users (consumers) can directly access it, or search for it via the search functionality provided by those services. The model architecture is shown in Fig. 10. Typical popular on-line sharing services are Flickr [1], for digital photos, and YouTube [2] for videos. In the same category we include also the popular social networking sites that allow content sharing, as part of the functionality, such as Facebook and MySpace.

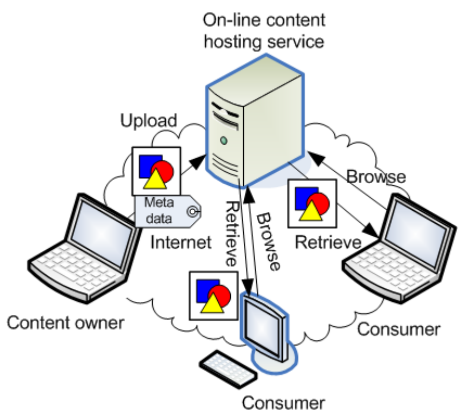

Fig. 10. *Model architecture of on-line content hosting/sharing services*

Most of these on-line services are web based, meaning that they are typically accessed via a web browser, so they utilize the Hyper Text Transfer Protocol (HTTP) [37], both for accepting new content (binary uploads) and presenting stored content to the consuming clients. Moreover, many of these services provide interfaces for interacting with dedicated sharing applications, in a machine-to-machine fashion, such as the Atom protocols, that we will analyze see in section 3.3.1.

Apart from the well know commercial services, such as Flickr and YouTube, there have been also many research prototypes in this area, trying to make mobile content sharing even more efficient and easy, among groups of users. For example,

[1] Flickr: http://www.flickr.com/
[2] YouTube: http://www.youtube.com/

Flipper [24] is a system that supports the group-centric sharing of content among a predefined list of people (e.g friends of ”buddies”), while MobShare [98] is a client-server system that utilizes current mobile phone and web technologies for immediate sharing of mobile images to an organized web album and providing full control over with whom the images are shared. Similarly, mGroup [56] allows story based communication spaces, where users can create media stories and can invite specific members to access them. The work of [VI] tackles also the group content sharing, but from a slightly different angle, by utilizing the home infrastructure.

Blogging is one of the latest major trends in sharing. Bloggers are driven to document their lives on-line, provide commentary and opinions as well as form and maintain community forums [76]. Typically, a blog is hosted by an on-line blogging service, where the user uploads his content and others periodically visit to read it. Being also web based, it supports any kind of multimedia content, thus it is suitable for content sharing. However, due to its public nature it is usually intended for sharing with the community, rather than small groups of family and friends. Mobile blogging is also possible as special smart phone applications allow the direct uploading of content to a blog and even some advanced solutions, such as [18], try to utilize context in order to automatically generate related metadata. A challenging issue with mobile blogging is that the cost can be inhibitive when using cellular packet radio for posting content, which might not be worth, assuming that a personal weblog has a limited number of daily visitors. The work of [V] tries to tackle this issue and proposes a solution that can reduce the usage of the packet radio service when blogging from a mobile device, while keeping though the same user experience that traditional weblogs provide.

Probably the most important disadvantage of hosting content to on-line services are the privacy issues. The authors of [95] point out the privacy invasions which are possible, when data mining on the server side is used on such shared content to build up profiles of end users. Moreover, as users upload content to such sites, there is an implicit loss of control for them and this can often have serious repercussions [95]. In a survey conducted by the U.K. Information Commissioner’s Office [109], it was shown that 1/3 of the young people surveyed have never read the privacy policies of such on-line services, and that 95% are concerned about the way that those websites use their personal information.

Based on our classification of sharing paradigms, as presented in section 2.3.1, on-line sharing services and blogs follow the *offering* paradigm.

3.2.3 Peer-to-Peer Content Distribution

Distributed computer architectures called ”peer-to-peer” (P2P) are designed for sharing of computer resources, such as digital content, storage, processing power, by direct exchange, rather than requiring the intermediation of a centralized server or authority [5]. Typically, such architectures are designed so that they can easily adapt to connectivity failures and support constantly changing number of participating nodes, while keeping their performance and connectivity. Content distribution is one of the most important applications of peer-to-peer networks, allowing nodes to cooperate in a distributed manner so that they can contribute, search, and obtain digital content [5].

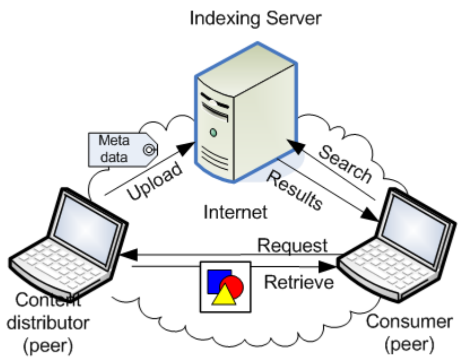

Fig. 11. *Model architecture of Internet peer-to-peer services*

Peer-to-peer content distribution systems are created by a network of nodes (peer computers) which form connections between them. This network, which is called ”overlay” network, is formed independently of the underlying ”physical” network, which is usually an IP network, such as the Internet [105]. Based on the centralization of their overlay network, P2P systems can be categorized as:

- Purely Decentralized, where all nodes are totally ”equal” and perform exactly the same functions (acting both as a server and a client).
- Hybrid, where most nodes behave as in the purely decentralized system, but some nodes (called ”supernodes”) perform some extra functions, for example behaving also as local central indexes.
- Centralized, where there is central server organizing the interaction between peers. They usually keep directories of metadata, with information about the

files available on the network, and the peer that stores them. However, file exchanges still happen in a peer-to-peer manner, between the end nodes, as show in Fig. 11.

Moreover, P2P networks are further categorized by their structure, depending if the overlay network is created in a ad-hoc manner or following some predefined algorithm and rules. The categorization is the following:

- Unstructured: the placement of content is completely unrelated to the overlay topology. Content discovery is typically performed by searching the network.
- Structured: The overlay topology is controlled and content files, or actually pointers to them, are placed at precisely specified locations. A mapping between content and its location, is formed in a distributed routing table, so that queries can be routed to the node with the desired content [70].

One of the main features of most P2P networks, including the well known Gnutella and Napster, is the ability to search over dynamic content [121]. Users are typically required to search for the content they are interested and the systems are efficient when multiple copies of the content exist in multiple nodes. This means that P2P systems perform well when the same files are available in multiple nodes which is, however, not typical for user-generated content. UGC is typically offered by one person, the creator, and in case of snapshot media it is consumed only by a very small amount of people (e.g. family and friends). Thus, the advantages of P2P networks are not fully utilized, when users share their self-created content. Moreover, people who wish to access the offered content must install special purpose software, which limits the audience capable of reaching the content [8].

Sharing commercial content, which interests much larger groups of people, makes much more effective usage of P2P networks, which are emerging as an alternative solution to solve the mass distribution of large digital content [91]. Solutions that integrate the functions of identification, tracking, and sharing of music with those of licensing, monitoring, and payment, appropriate for secure distribution of commercial content in P2P networks exist, such as the Music2Share [60] and CasPaCE [6].

On the mobile domain, P2P networks are still in a research mode, with the main work focusing on mobile specific optimizations of existing P2P protocols, such as in [20].

Actual implementations for consumer mobile platforms exist [34, 35], but they have not really found their way to the everyday life of end-users.

Based on our classification of sharing paradigms, as presented in section 2.3.1, P2P content sharing follows the *offering* paradigm.

3.2.4 Proximity Based Content Sharing

All the previously described sharing solutions assumed Internet connectivity, between two or more devices, for distributing digital content among end-user devices and on-line services. However, with short range radio technologies it is possible to also a establish a temporary, ad-hoc, network directly between two end-user devices within physical proximity, for transferring content. In such a scenario, as shown in Fig. 12 there is no need for connectivity to a public network, such as the Internet.

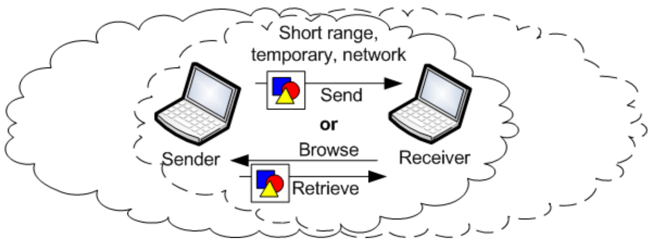

Fig. 12. *Model architecture of proximity based sharing*

Nowadays, modern mobile devices include a plethora of wireless radio modules, among which some support short range ad-hoc communication. The most widely used proximity technologies are the Bluetooth (BT) [14] and Wireless LAN (WLAN), which is based on the IEEE 802.11 standards [53].

Bluetooth is an always-on, low-power, and short-range radio technology for implementing Wireless Personal Area Networks (WPANs). Typically, devices need to be within 10 meters to communicate, at the speed of 723 kbps. Bluetooth can be used in many modes, which are specified in separate "profiles". The profile that is the most interesting for content sharing is the Generic Object Exchange Profile (GOEP). It is based on the OBEX [54] protocol and defines the methods and procedures to be used by applications dealing with object exchanges, such as files and media items. It allows pushing objects from one Bluetooth device to another, so in the scope of content sharing, that would be classified as *giving* paradigm, as it happens in a "face-to-face" or proximity manner. Due to its slow transfer speeds Bluetooth is typically suitable for limited number of media items, which are usually small in size, such as photos or audio.

WLAN has two different modes, the infrastructure and ad-hoc, depending on whether data is routed via an access point or directly in a point-to-point fashion. Typical indoor range is 50 meters and data transfer speeds go up to 54 Mbps, in the 802.11g standard. A WLAN network is identified by its service set identifier (SSID) and in ad-hoc mode the network usually has some temporary SSID used to differentiate it from other possible ad-hoc networks in proximity. The WLAN connection can be either open, without encryption, or it can use either Wired Equivalent Privacy (WEP) or Wi-Fi Protected Access (WPA) encryption. In its simplest form, the encryption mechanism requires that a pre-shared key is configured in all the participating devices. WLAN provides the physical and data link layers and does not specify any higher protocols. It is typically used with IP, as a network layer, and thus any IP based application can be utilized. Related to content sharing, a commercially available implementation of ad-hoc WLAN sharing is the Microsoft Zune player sharing functionality [17], that allows users to exchange music between to compatible portable media players.

Generally, it is possible that two devices, linked with an ad-hoc WLAN network, exchange content if one runs a web server offering content and another one uses a browser for consuming it (*offering* paradigm). Such a system is presented in [92], which is focused on sharing of personal content through wireless mobile devices. Full web server and development environment already exist, even for commercially available mobile platforms [81, 119], which makes it possible to also use remote file systems, such as the WebDAV [33], which is HTTP based. Moreover, as in ad-hoc networks there is no infrastructure, utilization of pervasive network connectivity protocols, such as UPnP [114] which we will analyze in 4.2, would provide even higher flexibility, for transparent content sharing.

As proximity sharing happens in a face-to-face and device-to-device manner, since it is based on short-range network connectivity, it is typically assumed that the users participating in the session know each other, thus they are family or friends.

3.2.5 Comparison

Putting together the core elements and characteristics of usage, for each one of the presented sharing methods, Table 1 presents a brief comparison of them.

Table 1. *Comparison of sharing methods in Internet & mobile domains*

	Messaging	On-line Services	P2P	Proximity
Sharing paradigm	Sending	Offering	Offering	Giving & Offering
Typical media category	snapshot	snapshot	commercial	snapshot
Typical content type	photos	photos & videos	videos & music	photos & music
Focus	user-centric	service-centric	content-centric	device-centric
Target recipient size	few persons	group of people or community	community	one person
Target users groups	family & friends	family, friends & community	community	family & friends
Limitations / concerns	media size	privacy	optimal for mass scale	mobile focused
Sample solutions	e-mail / MMS	Flickr / YouTube / Blogs	Napster / Bittorrent	BT OBEX / Zune Sharing

It is interesting to note that only the messaging services (e.g. e-mail and MMS) are "user-centric" focused, meaning that the sender addresses, as a recipient, specific people using, for example, their e-mail address or mobile phone numbers as identifiers. However, on-line sharing services could be characterized as "service-centric", as the users need to decide for which of the available services they want to be subscribers of and upload their content there. In the P2P networks, the focus is on the actual content, meaning that the users typically search for specific content (e.g. using the title of a song as the search key), and they do not really care who offers the content and vice versa, who is consuming content that they offer. This is why P2P can be characterized as ”content-centric”. Finally, in case of proximity sharing, the focus is ”device-centric”, as the users need to decide to which other device they want to send their content, or which device to browse for offered content. A simple example is giving content using the Bluetooth OBEX, which typically requires that, once the content to be shared has been specified, the user selects the target device from a list of scanned devices in proximity.

3.3 Key Protocols and Architectures

As the *offering* paradigm is the strongest in the previously analyzed solutions, in this section we will focus at the specific protocols and architectures that are the essential mechanisms for content offering, on the Internet. Most of the on-line Content Hosting/Sharing Services (3.2.2) are mainly ”living” on the World Wide Web (WWW), since it is the common platform for most Internet applications and users. This is why in this subsection we will focus on the HTTP based protocols and solutions which are related to content sharing.

3.3.1 Web Syndication Protocols

The Internet Engineering Task Force (IETF) Atom Publishing Format and Protocol (atompub) working group has specified protocols for editing, syndicating and archiving sources of episodic media content. Used mainly for news and blog sites, it follows the web feed paradigm which allows a client to follow changes and updates on a web site that it is interested into. Clients can ”subscribe” to feeds and periodically poll them to find out if changes or updates have occurred, in an extensive set of metadata associated with the feed entries.

The two main specifications are:

- The Atom Syndication Format [79], which describes ”feeds” consisting of ”entries”, each with extensible metadata. The description is based on the Extensible Markup Language (XML) and incorporates fields similar to the Dublin Core [28]. Atom feeds can be retrieved simply using HTTP GET with the URL of the feed. Feeds and their entries can be managed and manipulated using the Atom Publishing Protocol.

- The Atom Publishing Protocol [45], is the editing protocol for Atom feeds. Also based on HTTP, it is used for managing communication between a server and a client, and supports the normal HTTP POST, GET, PUT, DELETE verbs for the respective CRUD (Create, Read, Update, Delete) operations on Atom entries. It also benefits from features and optimizations generally available with HTTP, such as authentication, encryption and improved scalability through caching [III].

Atom protocols are nowadays used by most web sites that offer frequently updated content, such as blogs, social network based services, online photo albums and news sites. On the client side, it is supported by most web browsers, feed readers and online album sharing applications, both on the desktop and mobile domains.

Really Simple Syndication (RSS) [120] is an XML format similar to Atom Syndication Format and is used for the same purpose. However, Atom protocols are more strictly defined, while they are richer in functionality and detail than the older RSS [7]. Atom Syndication Format and RSS have been both widely used in web sites and nowadays are equally supported by most services. In content sharing, the biggest advantage of Atom protocols, compared to RSS, is the support in Atom Publishing Protocol for both upload and download of content and its descriptions, while RSS supports download only. This is why Atom is utilized in many client applications, desktop and mobile, for allowing content uploading directly to content sites, without the need of using their web page interface and a browser. As Atom protocols are more appropriate for content sharing, than RSS, and also standardized by a widely accepted body such as IETF, we choose to build the work of this thesis on them, rather than RSS.

Since the Atom publishing protocol is based on HTTP, any authentication mechanism compliant with the HTTP Authentication Framework [40] can be used for authenticating the users clients. When access authentication is required, at minimum Transport Layer Security (TLS) [30] with HTTP Basic Authentication [40] has to be supported.

Apart from their initial usage, for representing blog and content entries, web syndication feeds have been also used in many new contexts. Google Calendar[1] exports user calendar entries in Atom feeds, so they can be mashed-up with other sites and

[1] Google Calendar: http://calendar.google.com/

services. The recently specified FeedSync protocol [86] takes web syndication feeds even further, by defining extensions that enable loosely-cooperating applications to use Atom and RSS feeds as the basis for item sharing. That means enabling the bi-directional, asynchronous synchronization of new and changed items amongst two or more cross-subscribed feeds. That could apply to shared calendars, shopping lists, notepads, etc.

3.3.2 WebDAV

The IETF Web-based Distributed Authoring and Versioning (WebDAV) [33] protocol defines extensions to the HTTP/1.1 protocol that allows clients to perform remote web content authoring operations. Basic HTTP allows web clients to retrieve resources from a web server and also post new resources . The HTTP with the WebDAV extensions basically gives read-write access to the clients, in that way that it can be used as a remote file system for the Internet. Some of the key features of the WebDAV include overwrite prevents, with the usage of exclusive and shared locks, metadata (properties) and copy or move remote files, as well as versioning and access control lists, with some further extensions. WebDAV protocol is natively supported by major operating systems by default, e.g. Microsoft Windows and Apple Mac OS X, as well as web servers like the Apache HTTP server 2.0 [2] and on-line services like the Apple MobileMe [3]. Moreover, its applicability to mobile devices has been studied in [108] and it is nowadays natively supported in the Symbian based smart phones, running platform S60 [4] with Feature Pack 2 (FP2), .

As WebDAV is also fully based on HTTP, any authentication mechanism compliant with the HTTP Authentication Framework [40] can be used, for end user authentication, and it can also be combined with any of the HTTP compatible mechanisms for secure data transport.

When it comes to content sharing, WebDAV provides an excellent mechanism for moving content between a devices, i.e. a client and a server, with the simplicity of moving files from one system directory to another one. This way, users can easily upload their digital content to on-line services, without the need of special client

[2] Apache HTTP Server project: http://httpd.apache.org/
[3] Apple MobileMe: http://www.apple.com/mobileme/
[4] S60 platform: http://www.s60.com/

applications, as the WebDAV client is an integrated part of most operating systems.

3.3.3 Representational State Transfer (REST)

The Representational State Transfer (REST) [38] is an architectural style for distributed hypermedia systems, like the World Wide Web (WWW). REST specified a set of architecture principles which suggest how data resources are represented and addressed.

Key principles of REST architecture are:

- Application state and actual functionality are abstracted into resources. Any information that can be named can be a resource (e.g. a document, an image, a temporal service, etc.). Any concept that might need to be addressed and referenced must fit within the definition of a resource.
- Every resource must be uniquely addressable using a universal syntax, such as a Uniform Resource Identifier (URI) in HTTP.
- All resources must share a uniform interface for the transfer of state between client and the resource (hosted on the server). There has to be a set of well-defined operations and content types, while code on demand could be optionally supported.
- The protocol used for communication between the resource data provider and consumer has to be: client-server, stateless, layered and cacheable.

REST architecture is nowadays followed in many Internet services for loosely coupling different services, in order to provide rich data mash-ups [46]. The key is that services can provide simple interfaces, which transmit data over HTTP, without the need of an additional message or object exchange layer such as Simple Object Access Protocol (SOAP), and there is also no need for tracking sessions, via HTTP cookies. This paradigm of simple REST-based service composition, which is widely used on the Internet, is studied in [VIII] for enabling user controlled mash-ups.

When the REST architectural principles and constraints are applied, as a whole, it provides: ”enhanced scalability of component interactions, generality of interfaces, independent deployment of components, and intermediary components to reduce interaction latency, enforce security, and encapsulate legacy systems" [38].

We did this small presentation of REST architecture because the World Wide Web, on which most Internet sites are based, is the key example of a REST design. It follows all the key principals mentioned and it has proved how scalable it is, with almost all the Internet users utilizing it daily. Moreover, the two key content sharing protocols that we described earlier, Atom and WebDAV, are REST-compliant, as they also follow the principals (e.g. resource oriented, URIs for addressing, stateless and cacheable).

Systems which follow the REST principles are often referred to as "RESTful" [117].

3.3.4 Mobile Web Server

Web Servers have been typically used in static, powerful, Internet nodes. However, as the processing power of smart phones increased, research implementations of Web Servers for mobile devices emerged. For the S60 mobile platform there has already been a full port of the popular open-source Apache Web Server [81, 119]. By default, one would assume that having a mobile web server would allow the mobile phone to be reached, via a standard web browser, no matter its location, as long as there is cellular network coverage. However, as pointed out in [118], there are a few connectivity issues, when a mobile operator is involved. More specifically:

- Operators typically utilize firewalls that are configured to prevent all traffic, which is not initiated from inside the operator network, to reach their mobile domain.
- While Transmission Control Protocol (TCP) connectivity is supported in operator networks, it usually has some special characteristics that makes applications behave differently than expected. For example, a long idle time on an established connection might trigger a disconnect, based on the operator's policy configurations.
- Mobile phones on a mobile network are typically assigned a dynamic IP address, which is most commonly also a private IP address, behind a Network Address Translator (NAT).

All these issues actually make it impossible to reach a mobile web server, from the public Internet, in a real-life operator environment.

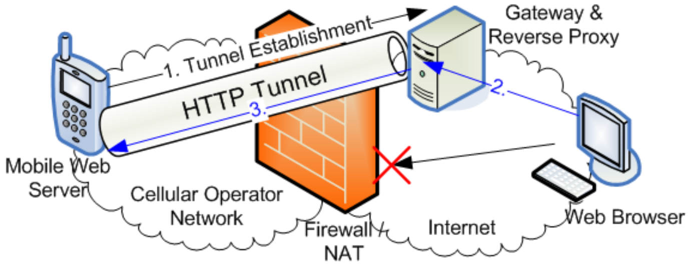

Fig. 13. *Architecture for connectivity to a mobile web server*

To overcome these problems, the [118] discusses how these issues can bypassed in order to allow traffic, from the public Internet, to reach a mobile server. The solution proposes the usage of static gateway or proxy infrastructure on the Internet, which is used as an end-point of a tunnel established by the mobile phone, as shown in Fig. 13. The gateway acts as a static reference point which proxies incoming requests to the appropriate mobile web server. Frequent, short, heart-beat packets (between the mobile phone and the gateway) make sure that the tunnel is kept alive.

This architecture opens a new dimension to content sharing, as it enables direct content offering from mobile smart phones, without the need to upload the content to an intermediate server. This could make the smart phone the sole device required in the content life-cycle, since it would be the device which captures, hosts and offers content, while it still has the required interface for the user to manage it. Moreover, as a mobile web server is essentially a full HTTP server, all the HTTP-based protocols and extensions which we previously discussed, such as Atom protocols and WebDAV, can be also used in the mobile environment, where the phone acts also as a server, not only as a client.

3.4 Summary

In this chapter we presented and analyzed the main content sharing solutions currently used on the Internet and mobile domains, namely messaging services, online content hosting/sharing services, peer-to-peer content distribution and proximity based sharing services. The *offering* sharing paradigm was identified as the strongest in this area, when sharing snapshot media with a group of family members, friends or even the wider community. We then presented the key technologies and architectures that are currently used, such as RESTful principals, Atom and WebDAV protocols, as well as the concept of the mobile web server, which is a promising future enabler for personal content sharing. The ”winning” protocols and solutions, when it comes to these domains, are the IP and more specifically HTTP based ones, as HTTP has succeeded to be the de-facto standard on the Internet, especially when mashing-up and coupling different services.

4. CONTENT SHARING IN THE HOME DOMAIN

For non-professional content creators, their homes remain the main hub of the content administration, editing and archiving, mainly by PC, of the content that they produced using their hand-held devices. In this chapter we study the characteristics of computer home networks, also known as residential networks, the main technologies and protocols used, as well as solutions for offering content directly from the home network.

4.1 Home Networks

Traditional consumer electronics devices, such as television sets and audio systems are getting new functionalities and features, like the ability to show digital images, play music from digital media, stream media from the Internet and digitally record (”time shift”) live broadcast programs. Even more, many of these new home devices are not functioning only independently. High-end models can discover each other and in a service oriented architecture paradigm combine their services in order to provide new levels of wellbeing and entertainment for the people possessing them. These scenarios are based on the assumption that modern residences are equipped with some type of home network.

A **home network** can be defined with the following two definitions, the first being technical and the later one being more social:

- A home network interconnects electronic products and systems, enabling remote access to and control of those products, systems and any available content such as audio, video, or data [83].
- the networked home is defined in terms of two major components: an internal household network, which primarily consists of network relationships with

family and friends and social circles; and an external network connecting the home to outside agencies [115].

As broadband Internet connections are becoming a reality and available to a high percentage of the population [103], the usage scenarios of home networks have also changed, as they are not just printer sharing, web browsing and e-mail communication. Downloading content for entertainment, watching it on the large living-room television set, or having two-way video calling is now a reality for many, even though there is significant household effort not just to coordinate the home network usage, but also to set it up and maintain it [47]. One thing is for sure, users want technology to be simple, be invisible and work [66].

Based on recent market forecast [41], the worldwide home networks were almost 100 million and they are expected to double by year 2011, as shown in Fig. 14.

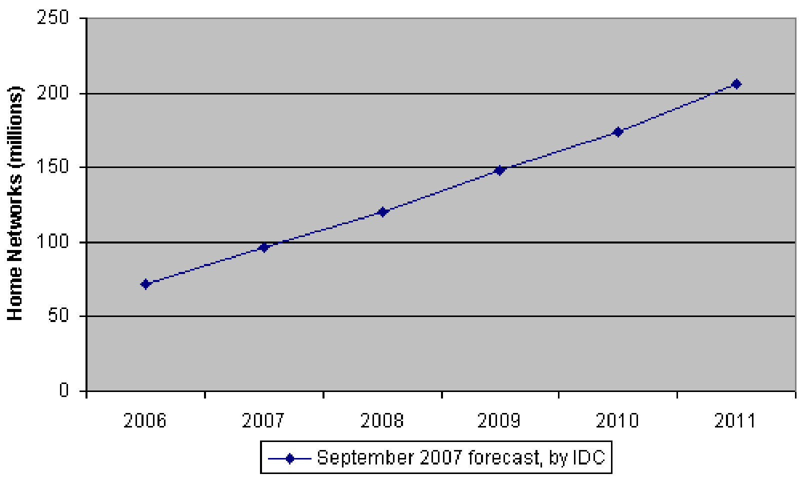

Fig. 14. *Worldwide households with a home network*

There are many different network architectures and technologies that can be found in a home network, as presented in [11, 107]. In this thesis, for simplicity reasons, we will assume a generic model, that encompasses most of the typical home network setups. As shown in Fig. 15 we assume that the Internet connectivity is provided by an Internet Service Provider (ISP), which is delivered to the home over a cable or telephone network (for example via an Asymmetric Digital Subscriber Line) and terminates, at the customer premises, at a home gateway. In the home network, connectivity is usually provided either by a fixed cable backbone (such as Ethernet) or nowadays it is very common that the home gateways also act as wireless LAN (WLAN) access points. So, home devices can communicate to each other, in a wired or wireless manner, and have connectivity to the public Internet. Also, in the context of this thesis we assume that the main networking protocol used is the Internet Protocol version 4 (IPv4), and we do not study the version 6 (IPv6), since it is not, yet, supported by many consumer electronics devices.

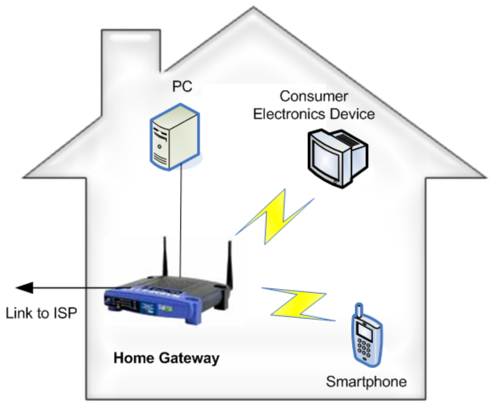

Fig. 15. *General home network architecture*

From the networking point of view, the ISP would typically assign one public IP address to a home network and that would be assigned to the Wide Area Network (WAN) interface of the home gateway. Then, the gateway usually acts as a Network Address Translator (NAT) [104] and implements a Dynamic Host Configuration Protocol (DHCP) [32] server, that provides private Internet Protocol (IP) addresses [21], to the devices connected on the home network, as shown in Fig. 16.

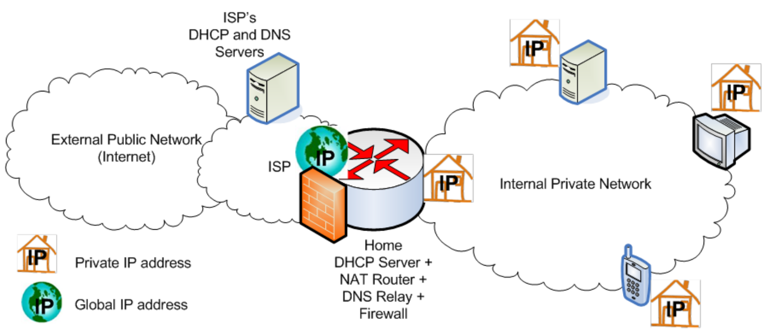

Fig. 16. *Typical network topology of a home network*

Additionally, the home gateways typically act as Domain Name Service (DNS) relays, so that in-home DNS queries are redirected to the ISP DNS server, and as firewalls so that they would block undesired external traffic from reaching the home devices.

4.2 Universal Plug-and-Play (UPnP) Protocols

One of the visions of home networking is to provide ubiquitous connectivity and interoperability among devices of different manufacturers. Many protocols exist for device and service discovery [50], and up to date as many as 50 standards and organizations are related to home networking [93]. However the dominating protocols, supported by more that 860 partners, have been those of the UPnP Forum [1]. The UPnP architecture enables pervasive peer-to-peer network connectivity of PCs, intelligent appliances and wireless devices [74]. UPnP is versatile and designed so that it can run on a variety of devices, including resource constrained mobile smart phones [48]. In this section we will briefly describe the core specifications of UPnP protocols, which are important for this thesis.

4.2.1 UPnP Device Architecture

The UPnP Device Architecture (UDA) [114] provides support for ”invisible” networking, meaning zero device configuration and automatic device and service discovery, for many device categories. Devices can dynamically join a network, obtain an IP address, announce their name, report their capabilities and discover the presence and capabilities of other devices, connected to the same network. Devices can also disconnect and exit the home network without leaving any state information.

In UPnP scenarios devices are controlled by clients, which are called ”Control Points”. The control point is responsible for coordinating the operation of a UPnP device in order to achieve the tasks and the function that the end user desires. UPnP devices do not directly interact with each another, rather the coordination between them is executed and synchronized by the control point. In Fig. 17 the layers of UPnP networking are presented, in a ”bottom-up-approach”, that is starting from the lower level connectivity issues, up to presentation.

[1] UPnP Forum: http://www.upnp.org/

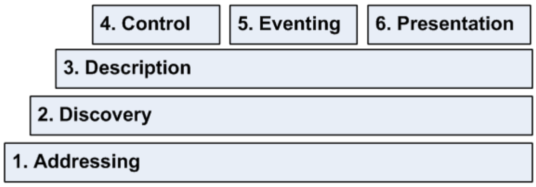

Fig. 17. *Layers of UPnP networking*

In more detail, the each step has the following functionality [9, 59]:

Addressing is the very first step towards UPnP networking. Every UPnP device needs to automatically acquire an IP address, before it can communicate with any other entity. Control points and devices get addresses for a DHCP server, if available in the network. If not, then they should select an address based on Auto IP, which is an implementation based on [21]. Auto IP essentially suggests that a node picks an address in 169.254/16 range and checks to see if it is used, using the Address Resolution Protocol (ARP).

Discovery of network-based resources is the next step. When a device joins the UPnP network, the discovery protocol allows the device to advertise its services to control points across the network; and allows a control point to search for available services. This is done by sending multicast search message, using Hyper-text Transfer Protocol (HTTP) over User Datagram Protocol (UDP) over IP, using the HTTP Multicast (HTTPMU) [114]. Devices that receive the search message reply back in a unicast manner. The discovery multicast address, and the format of the advertising messages defined by the Simple Services Discovery Protocol (SSDP) [114]. A UPnP control point can limit the search parameters and just look for devices of a particular type (such as just audio devices) particular services (such as clock services) or even a particular device.

Description covers the format of the documents used to describe UPnP devices and the services provided by them. If a control point needs to know more about the services offered by the device it needs to request the description document that is in Extensible Markup Language (XML) format. This document describes the physical device and all its logical embedded devices, services, manufacturer information, etc. Service description lists what is implemented by a service. That includes the set of actions and methods implemented, which may have zero or more arguments (parameters). Each argument is also tied to a state variable. Variables can be read by control points, and as we will see later, they can ”subscribe” so that they are automatically notified when a variable changes. Note that this service description information is defined by UPnP Forum for a standard service, but if a vendor would like to create a non-standard service, then the vendor should provide this information.

Control describes the remote procedure call mechanism, used by control points, to invoke services offered by UPnP devices. This is done using the Simple Object Access Protocol (SOAP) [16]. Through the use of SOAP a control point can query or change the elements in a service's state table, such as turning the device on or controlling the volume of an audio system. The control point creates the XML document that contains the commands and posts it to control element of the device to be controlled. SOAP messages are delivered on top of HTTP.

Eventing defines how control points are notified about changes on the state of devices. Once a device or control point subscribes to the services of a UPnP device, it can stay informed of the state of those services. They can subscribe by using the event notification service URL (provided in the service description) and are then notified by the UPnP device once the state of the services changes. For example, subscribing to the events of a television set, a control point would get a notification when the television is turned on, or off. Or, it can be notified when the temperature of a room change, if such a service is offered by a UPnP enabled home air-conditioning system. Event messages are delivered via HTTP using the General Event Notification Architecture (GENA) [114].

Presentation defines how a UPnP device may use standard web protocols to provide a typical web page that can be accessed via any web browser. Basically, it is allowed for a UPnP device to include, in its device description, a URL that points to its own web server and links to a standard web page, which can be, however, dynamically updated. This way, a user can use a standard web browser in order to access information, and maybe also control, a device.

These basic steps, of the core UDA, specify only how devices can join the network, discover each other and how to perform actions. But, it does not specify the actual messages or data exchanged between the devices, or the functionality expected by them. These are topics that separate specifications, still under the UPnP Forum, are handling. Next, we will briefly present two of them, which are essential for this thesis.

4.2.2 UPnP AV Architecture

The UPnP Audio/video (AV) Architecture [113] defines the general interaction between control points and UPnP AV devices, such as media servers and renders (Fig. 18). It is independent of any particular device type, content format or transfer protocol. The architecture allows compatible devices to support multiple formats of media content types and also different types of data transfer protocols, such as HTTP or Real-time Transport Protocol (RTP). A typical UPnP AV scenario suggests the transfer or streaming of multimedia content (such as movies, images or songs) from one device to another, for copying or rendering.

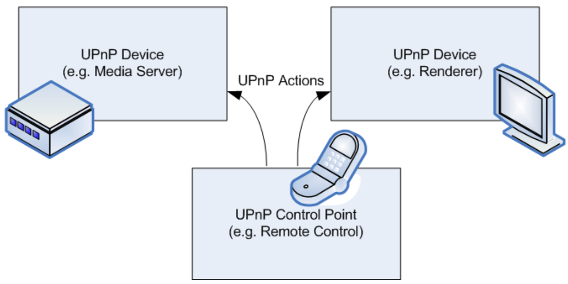

Fig. 18. *Typical UPnP device interaction model*

Additionally, the MediaServer specification [112] suggests a general-purpose device that can instantiate any repository device that holds and stores AV content, such as media, to other UPnP AV devices on the home network. The stored content is exposed and offered via the ContentDirectory service (CDS) [111]. CDS provides a uniform, and well specified, mechanism for control points (such as remote controls with a rich user interface) to browse the content available on the server and obtain detailed information and metadata about their respective individual content objects. Moreover, it specifies a lookup and storage service that allows clients to locate and store individual objects, such as songs, movies, and pictures that the server is capable of offering. The metadata defined in CDS includes fields from the Dublin Core [28] metadata and DIDL Lite [55].

The UPnP AV architecture is important for content sharing, in the home domain, as it is the main standard for content distribution among home devices. It is already supported by many, multimedia focused, networked consumer electronic devices, such a media renderers and advanced audio systems, and at the same time implemented as part of most network attached storage (NAS) devices available on the market.

4.2.3 UPnP Internet Gateway Device (IGD)

The UPnP Internet Gateway Device (IGD) [110] is a UPnP device that is located on the ”edge” of the residential network, that would mean between the home Local Area Network (LAN) and the Wide Area Network (WAN) that provides the connectivity to the public Internet. As a physical location, IGD typically resides on the home gateway, which typically implements the functionality that the IGD specification requires, but in theory it could also be a piece of software installed on a PC.

The UPnP IGD Standardized Device Control Protocol specifies a collection of devices and services which enable compatible UPnP Control Points to control the initiation and termination of data connections, going through the home gateway and at the same time monitor the status and events of these connections. Moreover, it allows administration of the configuration services provided by the gateway, for example the configuration of the Dynamic Host Configuration Protocol (DHCP) server or Dynamic Domain Name Service (DNS) relay. But, one of the most important features is that it also provides a functionality which allows the control points to administer the network address translation (NAT) on the IGD device. This means that a UPnP IGD control point can make requests to an UPnP IGD (i.e. the home gateway), in order to allow incoming traffic from the public Internet and forward it to a specific in-home device. Basically, this allows the configuration of the port forwarding functionality (which we present later in section 4.5.1) and the home firewall.

4.3 Digital Living Network Alliance (DLNA)

The UPnP protocols do not strictly specify the expected capabilities of home devices. For example, UPnP does not specify how devices physically connect to the home network, or what kind of media files a UPnP AV renderer should be able to ”play”. This led to incompatibilities and problematic user experience, as the UPnP certification was not enough to guarantee that two (in theory) compatible devices would actually cooperate as the user would expect.

In order to guarantee better interaction among home devices, consumer electronics, PCs and mobile phones, the Digital Living Network Alliance (DLNA)[1] was formed

[1] Digital Living Network Alliance: http://www.dlna.org/

in 2004. DLNA released guidelines [31] with stricter information on how to build interoperable devices for the networked home. DLNA guidelines still heavily utilize the UPnP protocols but on top of that they define the issues that were not covered there, such as the physical connectivity, security pairing of home devices, mandatory media transport protocols and media formats. The DLNA guidelines were based on some core use cases, which are mainly focused around digital media distribution in the core home network. However, they do not cover or address any use cases related to content distribution out side the core home network, that would require exchange of data between the home and a remote entity. This scenario, or remotely accessing home hosted content, is an essential element of the ”Extended Home” concept, as presented in the next section.

4.4 The Extended Home Concept

The digital home research has been long focused on combining communication, multimedia and home automation networks, promising to simplify the everyday life of the users. But, the main area of research has been the devices and the technologies within the physical home. The ”extended home” concept places the user in the center of the home ecosystem, giving focus on how the people can access their home-hosted services and content, regardless of their location or device. Users shown not care about the underlying technology [90].

One can consider extending the home network by [3, 78]:

- Spatial extensions
  - Users taking home with them when not at home (e.g., access to home information, remote home control)
  - Extending the (closed) home network to multiple homes or home-like sites (office, car, etc.)
- Functional extensions
  - Extending the home interface to external services

As shown in Fig. 19, the federation of all the domains, linked to the core home network, in a virtual environment constitutes the ”extended home”. The goals is to ”distribute” the resources of an ”evolved” home network over several physically separated domains, allowing the user to have similar application and service usage experience as if he was accessing services from within the home core [89].

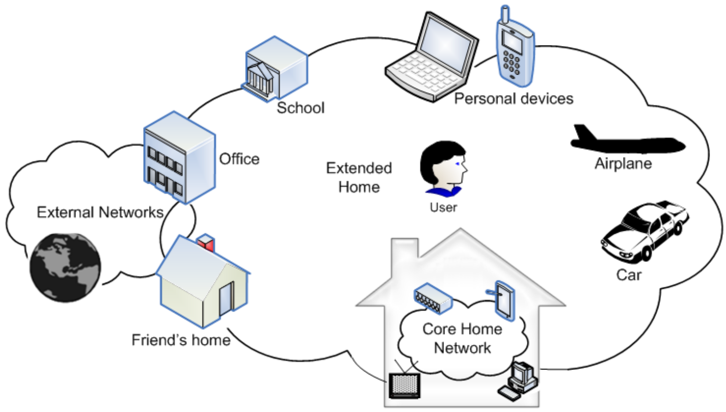

Fig. 19. *The Extended Home concept*

The vision is that the extended home environment will handle the issues, at network, service and application level in order to provide both service nomadism, allowing access to the home domain services from any public service providers to which a user is subscribed, and user nomadism, enabling roaming across home domains [89].

An important enabler for the extended home concept is the opening on the home network to external entities and networks, in order to make its devices and services remotely accessible. This ”Remote Access to Home Networks”, is explained in the next section.

4.5 Remote Access to Home Networks

As home networks get more and more advanced, with fast always-on Internet connectivity, hosting many devices and services, users have the need to access some of them while they are also away from home. This capability of accessing, from an external Internet node, devices and services that are located in the home network, is called ”Remote Access to Home Networks” [11]. The external device could be any Internet connected device, such as an office computer, a public Internet Cafe PC, a portable Personal Digital Assistance (PDA) or a mobile phone.

The remote access to home is not a straight forward procedure, due to the implications that the NAT introduces [100], which break the Internet end-to-end reachability and addressability. As in-home devices are assigned private IP addresses, they cannot be directly accessed from the public Internet. As mentioned in 4.1, there is typically only one (public) globally routable IP address assigned by the ISP, and this is typically the address of the home gateway. Thus, this is the only home device that can be reached from the public Internet. There are three main techniques, in the IPv4 domain, used to over come this problem.

4.5.1 Port Forwarding Technique

To overcome the routability problem, that the NAT introduces in the home networks, the ”port forwarding” technique is typically used in combination with the NAT functionality of the home gateway. As shown in Fig. 20 it suggests the creation of a mapping table in the NAT router, i.e. home gateway, which allows a request that is directed to a specific TCP/UDP port of the public IP address of the gateway to be forwarded to a port attached to any of the internal IP addresses, according to rules predefined by the user.

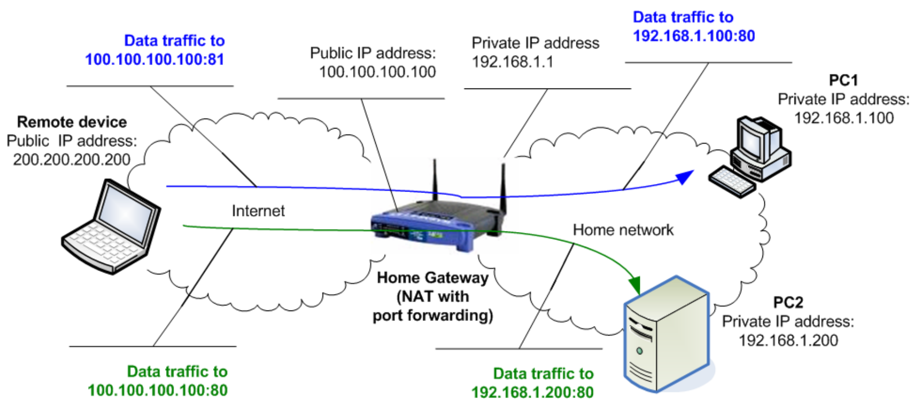

Fig. 20. *Port forwarding example in a home network*

The most important advantage of port forwarding is that it works on TCP and UDP protocol level. This means that once the rules are correctly set, almost all the applications and services can work transparently, as if the NAT was not there. Moreover, since the forwarding is not done on a very high level, there is no need for significant processing power at the gateway device, thus it can run on an inexpensive embedded hardware platform. This why it is practically deployed on all home routers and gateways currently available on the market and used in most homes with a broadband Internet connection. On the other hand, configuring the NAT rules requires network administration skills and knowledge that the average home user is not capable of. However, in some application cases solutions like the UPnP IGD, that was presented in 4.2.3, ease the task of configuring port forwarding, for the end user.

4.5.2 Virtual Private Network (VPN) Technique

The Virtual Private Network (VPN) [99] techniques allow a remote client to establish a secure communication channel to a home network, over a public and shared network such as the Internet. VPN is mainly used by corporations that need to securely connect their different site networks or allow their employees to remotely work on their main network. Nowadays, some home gateway devices also provide VPN

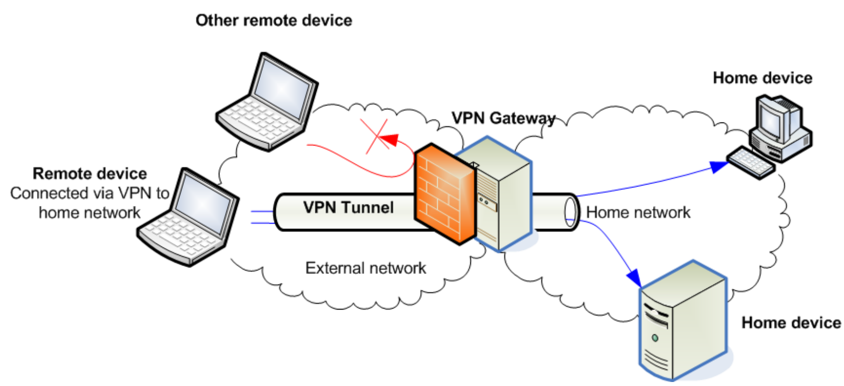

Fig. 21. *Virtual Private Network (VPN) to the home network*

server functionality. VPNs have the capability of providing the same security and management policies as the home network.

The client establishes an end-to-end tunnel to the VPN gateway and can then use all the resources of the private network, as if it was directly connected there (Fig. 21). Moreover, a remote client can also get a private IP address, from the home address range and communicate with the rest of the home devices using any IP based protocol and service. Since the tunneling mechanism hides all intermediate transit nodes, protocols which require a small Time to live (TTL) value, such as UPnP, could still work on top of a VPN connection.

4.5.3 Application Layer Gateway Technique

An Application Layer Gateway (ALG) is a gateway from one network to another for a specific network application [85]. In the context of the home domain, it can be used on the edge of the home network, for relaying or proxying traffic between the wide area network and the in-home network. An example would be an HTTP gateway, that would accept requests on the Wide Area Network (WAN) interface of the home gateway and forward them requests to some in-home web server, as shown in Fig. 22.

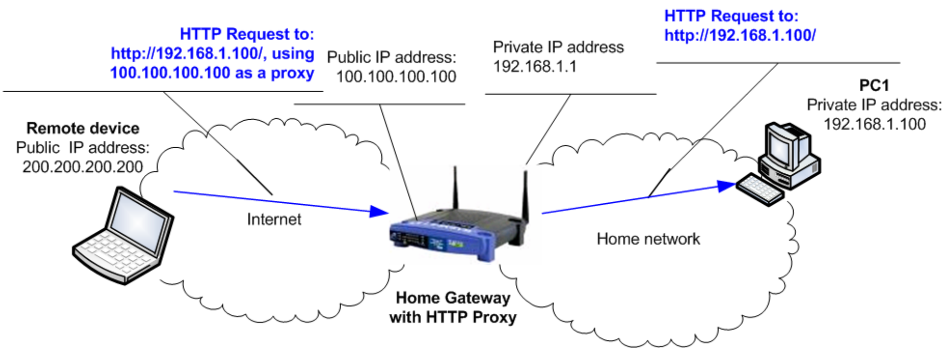

Fig. 22. Application layer gateway

The HTTP ALG/Proxy solution solves one of the biggest disadvantages of VPNs, which is the requirement for special VPN client software on the remote device. Almost all Internet enabled devices have a web browser and HTTP stack, so this could be the user interface and transport protocol for accessing the home resources.

4.5.4 Challenges with Remote Access

Choosing the appropriate remote access technique, for accessing a home network, is not a simple choice, as there is not ”standard” or ”winning” solution. Each one of these basic solutions has some advantages and disadvantages, which should be considered when designing the application or service that is supposed to use them, in order to decide which solution is the best for the given scenario. Here, we will discuss optimal operating functions and challenges for there solutions.

Type of traffic: Port forwarding works on top of IP layer, meaning that almost all TCP and UDP based protocols would work via NAT with port forwarding. VPN solution works in even lower layer, so that essentially any type of IP traffic can be essentially work transparently. On the other hand, an application layer gateway works on the higher application layer and it is bound to a specific protocol, higher than TCP or UDP, that it is designed for (e.g. HTTP proxy, designed for web traffic).

Compatibility with UPnP: UPnP technology was envisioned to be deployed in local area networks. This initial design goal lead to decisions are which make it challenging, nowadays, to expand the original scope of UPnP beyond the physical boundaries of local area networks, such as those found at home. The most important challenge is related to the device discovery described in the ”discovery” step of 4.2.1, which involves multicast messages. Multicast traffic is challenging to forward beyond the home network due to the fact that typical Internet routers are configured so that they discard it. And the typical port forwarding and application layer gateway techniques do not help with this, rendering them inappropriate for accessing a UPnP home network, from a remote device. The VPN technique is a solution that is not affected by this problem, since the connection appears as a tunnel that hides all the intermediate routers. However, in practice UPnP might not be usable in a VPN environment due to long delays caused by the bearer latency on some network segments (e.g. radio access networks like GPRS), and the unreliability of the User Datagram Protocol (UDP), which is used as the transport protocol in UPnP discovery phase [II]. Most UPnP devices and applications come with a very short, fixed, device search timeout period, which would render them unusable in most VPN environments, on top of a mobile network. Moreover, since VPN transparently forwards all device advertisements, from the home network to the remote, it would not provide the optimal user experience, as the remote user would be prompted to use devices that might not make sense remotely (for example, display photos on a home TV set, if the user is not at home). All these issues of VPN are addressed and solutions are proposed in [II].

Application Protocol Requirements: Because port forwarding and ALG techniques rely on address mapping, between internal and external addresses, there are some considerations [100] that need to be taken into account, when designing applications and protocols that would be used in network setups, with these elements. The single most important one is the guideline that DNS names, and not IP addresses, should be used in the payload of the messages exchanged. This is one more reason why UPnP protocols cannot be used in these environments, as it actually uses IP addresses in the payload of the messages. However, the VPN solution is not actually affected by this issue, and does not impose any limitation or requirements on the protocols that can be used over a VPN tunnel.

Addressing scheme in/out home: The addressing scheme, for accessing home hosted devices and services, is different if the client is in the home network or trying to access it from outside, for the port forwarding and ALG techniques. For example, a service that might be accessible at the internal address http://192.168.1.100:80/, needs to be accessed using the URL: http://100.100.100.100:81/ if the client is outside the home network (example of Fig. 20). Obviously, this creates confusions to the users and in some cases they might need to have duplicate configurations at their devices. This is the problem that [I] addresses, without the need of any extra client software. VPN is not affected by this issue, as addressing is the same no matter the physical location of the client device.

Functionality & Configurations: Looking at how those basic remote access techniques can be deployed in real life, we can say that port forwarding requires functionality to be embedded only at the home gateway, where also configurations are needed (port forwarding mappings). Similarly, for the ALG, functionality is implemented there and so are the configurations. However, in the case of VPN special software is required at the both ends of the tunnel, namely the VPN end-points, meaning the home gateway as well as the remote client. The client device needs, apart from the VPN client software, the appropriate settings (e.g. security certificates), for establishing a connection.

Complexity: The simplest solution to implement is the port forwarding. It works on the TCP/UDP layer and does not require heavy processing power, as it basically only changes IP headers and forwards the traffic. This is why it is widely deployed in most NAT devices available on the market. An ALG requires more complex implementation, as it is specific to a protocol. Also, more processing power is expected from the hosting hardware device, as all IP packet payloads needs to be parsed. Finally, the VPN can be considered the most ”heavy” solution, as it is usually combined with encryption mechanisms, that require intensive processing power.

Security (Encryption & Authentication): As remote access implies that traffic (between the client device and the home network) is routed through the public Internet, it means that some security considerations need to be taken into account. Since the home network is hosting private data, it would be sensible to require encryption in the exchanged traffic, so that no intermediate entity can intercept it, as well as authentication of connections, so that only trusted clients can connect to the network. In the case of port forwarding, the encryption and authentication should be handled by the two communicating end-points, that is the remote client application and the home device that host the offered service (e.g. a media server), as the NAT with the port forwarding functionality, is transparent and cannot add any encryption functionality to the exchanged data. This is an important limitation of this solution, since it assumes that the in-home services and devices are ”remote access” aware (i.e. supporting encryption and authentication), something that is not a reality, at least in existing home devices. As mentioned earlier, UPnP protocols were designed for local network usage and thus most devices or service do not support any encryption, since the home environment is assumed secure. However, in the case of VPN and ALG the situation is different. There, the encryption and authentication need to be handled by the VPN gateway end-point and the ALG, respectively, on behalf of all the in-home devices. This means, that those solutions can work with legacy in-home devices, that are not ”remote access” aware. The secure tunnel is terminated at the VPN gateway or the ALG, and traffic does not need to be encrypted in the home network. Usual encryption mechanism for VPN is IPSec, while for ALGs that utilize the HTTP protocol, Secure Socket Layer (SSL) is typically used.

Scope of usage: As a general, high level, classification of the different techniques, we could say that VPN is suitable for remotely accessing the whole home network, in a totally transparent way. The port forwarding technique, is suitable for higher level access of any TCP/UDP home hosted service. And finally, the ALG is suitable for accessing a very specific home hosted service, that is compatible with the functionality of the used ALG (eg. a web service that is used in combination with an HTTP ALG).

Table 2 summarizes the specific characteristics of each solution, as presented in this section.

In is important to note that the solution characteristics and limitations mentioned in the section refer to the ”core” or ”elementary” solutions available for remote access to home networks. There has been a lot of research work for coming up with ”tweaked” and modified solutions that solve some of the presented problems, usually with the addition of new element enhancement or modification. We will present the ones that are more relevant to content sharing in the next section.

Table 2. Comparison of core remote access techniques

	Port Forwarding	Virtual Private Network (VPN)	Application Layer Gateway (ALG)
Type of traffic	Any TCP or UDP	Any IP	Only specific protocol
Compatibility with UPnP	No	Yes (in theory)	No
App. protocol requirements	No addresses in payload	No requirements	No addresses in payload
Addressing scheme in/out home	Different	Same	Different
Functionality required at	Only gateway	Gateway and remote client	Only at ALG
Configurations required	Only gateway	Both VPN endpoints	Only at ALG
Complexity	Very low	High	Low
Encryption	At all in-home applications	Only at VPN endpoint	Only at ALG
Authentication	At all in-home applications	Only at VPN endpoint	Only at ALG
Scope of usage	Accessing any service	Accessing whole network	Accessing a specific service

In this section we made the assumption that every home network is assigned a public IP address, by its Internet Service Provider. However, that are cases that home users cannot get public IPv4 from service providers, especially in developing countries. In those situations Network Address Translation (NAT) and port forwarding are used in the ISP level, but this results into multiple homes ”sharing” the same public IPv4 address. Solutions for solving this kind of special situations have been proposed, such as in [51], where IPv6 and IPv6 transition mechanisms in cooperation with existing VPN solutions are suggested.

4.6 Content Offering Directly from Home

4.6.1 Motivation for Offering Content Directly from Home

It is estimated that the next decade many homes may have greater amounts of personal non-commercial digital content than commercial content [23]. That means that a large amount of user-generated content would be available on a networked home and thus, we could argue that offering it directly from the home network, for remote consumption by family members and friends, makes sense.

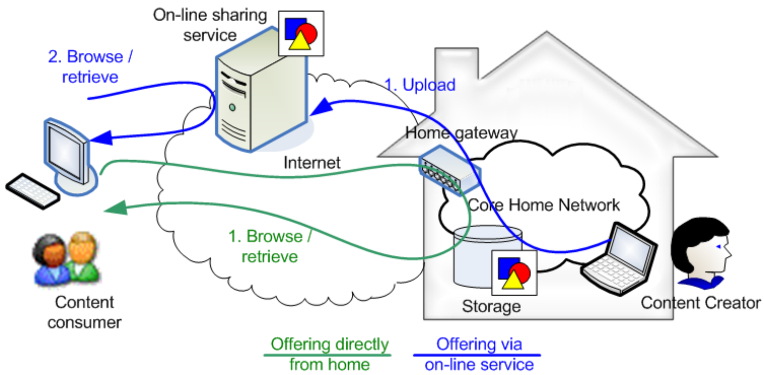

Fig. 23. Offering content directly from home vs. uploading on-line

There are some advantages if content could be directly offered from home vs. uploading it to an on-line sharing service on the Internet, as shown in Fig. 23. More specifically, the following key argumentation can be given:

- Capacity: The amount of storage at home is virtually unlimited, and very cheap. Users can get hard disk drives with capacity of 1 Terabyte for about 100 EUR, already today. There is no service on the Internet that offers similar space/price ratio.
- Privacy: Keeping content hosted at home gives full administration and legal rights to the owner. Uploading content to Internet sites is linked with an implicit loss of control, which can have serious repercussions [95]
- Real-time data access: Keeping the original content hosted at home and offering it directly from there it has the benefit of "real-time" access. The latest content is always available to the consumers and not a "snapshot" instance of it

which was uploaded to an on-line sharing service. So, if the content is updated, the latest version is instantly available for offering.

- Common repository: All content (shared & non shared) stays at one location, the home and it is administrated via a common interface. Uploading part of the content to the Internet would mean that there is fragmented storage space and the user needs to use multiple services and sites for hosting content at different locations.
- Commercial content: Event though slightly outside the scope of this thesis, apart from user generated content the home owner might want to remotely access also some, legally acquired, commercial content. Uploading it to an Internet service is legally forbidden. Consuming it from home, but still not sharing it with others, is usually not violating copyright laws, even though one might say that there is a thin line in these scenarios.
- More than media: Looking a bit further, beyond user generated multimedia content, there might be content at home, such as sensor data, that does not follow the paradigm of object or file and can be uploaded on a site. This is content that makes sense only when needed, and thus this kind of data does not make sense to be constantly uploaded to an on-line service.

4.6.2 Solutions for Home Content Offering

Though a few NAT traversal techniques, such as Session Traversal Utilities for NAT (STUN) [94], TCP hole punching [39] and the HomeDNS [I], have been studied to solve the communication problems of devices behind NATs, a fully applicable solution in all possible environments does not really exist [52]. As we will see in this section, there has been a lot of research in this area, which has been recently moving from the low networking issues of remote access, to the higher level issues of content sharing at the extended home. That is, studying how content, hosted at the home, can be offered to remote users, those being the home owner, family members, or the wider community.

The authors of [67] propose a proxy-based distributed scheme for streaming services among UPnP home networks. They suggest the extension of the home gateway with a UPnP-compatible protocol that relays SSDP messages, in a similar manner to our work presented in [II]. This allows interconnection of multiple homes, which have a special new element (called "SHARE module") on their home gateway, for sharing and streaming content from a UPnP AV server, located at one home, to UPnP AV renderer located at another home. The proxying functionality solves the challenges of the "problematic" SSDP multicast UPnP traffic, but the solution does not address the issues of specific access rights to specific media containers and fine-grained access control[1] (i.e. which remote users have access to which specific media items, on a UPnP AV Server). Moreover, the solution is focused explicitly on interconnection of homes, assuming a static home-to-home configuration, and does not address the use cases of a remote device (e.g. mobile phone) accessing the home network. Thus, it seems more appropriate for interconnecting two homes of the same family, such as linking the main home with the summer cottage. Similar solution is presented in [22], where two statically linked UPnP home networks are considered.

Other solutions suggest the interconnection of a single remote device to the home network, such as in [84] and [49] which propose the usage of Session Initiation Protocol (SIP) for enabling remote access to home based DLNA/UPnP devices, utilizing as a security enforcement the user authentication method specified in the SIP. These solutions authenticate users, but still they do not provide any mechanism for fine-grained access control, to specific content, that would be required for opening the home hosted content to people outside the family, such as friends. The same applies for the solution [61] which suggests the creation of Virtual Private Network (VPN), between the home network and the remote device, for remote content streaming and consumption. Similarly, the [52] proposes the usage of JXTA [44] as an overlay network for linking a device to the home network.

The author of [116] is introducing remote content sharing, from a UPnP AV server, with the notion of groups. Groups can include PCs and mobile phones corresponding, say to the members of the family or a social groups of friends. However, the system allows specific groups to access specific UPnP devices in the home, and thus accessing all the content that they might host. In [IV] we are taking into consideration the social aspects of content sharing, where the home owner might want to give remote access to specific home hosted content to his friends but not the whole media

[1] Access control is the activity of permitting allowed users, devices or processes certain access operations to specific resources and processes on the network, while keeping the unwanted ones away [66].

server. The solution suggests exporting specific home hosted content, residing on a UPnP AV server, to external users via a proxy that filters the exposed content, using authentication which is based on pre-distributed credentials. An extension of this solution, as presented in [VI], could be used for allowing group based content sharing, where the home infrastructure serves as a repository for multiple, remote, users.

To access specific content, hosted on a UPnP AV server, the user needs to know the media servers name or search for it on the network. In [87] the authors propose a system where the user can access the content without any awareness of media servers location or name, utilizing a logical entity, called Virtual Media Server, which provides aggregated information such as all available media servers, content grouping, etc. This entity does not have any storage, but it utilizes the storage capacity provided by standard UPnP AV servers in the home network. This approach is interesting for more advanced scenarios where the end-user is not expected to know the details and devices of the home network (e.g. user being a friend and not the home owner).

4.7 Summary

In this chapter the concept of the home network was presented and the characteristics of a typical home were analyzed. Then, the UPnP protocols, which are the ”de-facto” standard in the domain, related to digital media were presented. The Extended Home concept, which adds spatial and functional extensions to the core home network, was introduced, followed by the notion of Remote Access which is the key enabler for the concept realization. The three core remote access techniques were analyzed, namely port forwarding, VPN and Application Layer Gateway, along with their related benefits and challenges. Finally, previous work and solutions for remote content sharing, in a UPnP/DLNA enabled environment, was presented.

5. SEAMLESS CONTENT SHARING

5.1 The Concept

As presented in the previous chapters, users store their content in multiple locations, such as home, on-line sharing sites and mobile devices. Sharing via those repositories and services is done using domain specific technologies and protocols, as shown in Fig. 24.

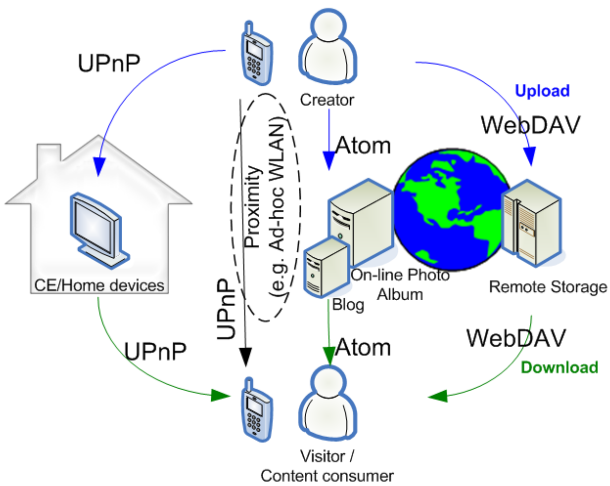

Fig. 24. *Multiple sharing methods / protocols*

One cannot really pickup any ”winning” sharing method or solution, as each of them has its advantages and disadvantages. They are all designed for specific sharing scenarios and specific sharing target groups (e.g. family, friends or community). So, it is not expected that one solution will dominate or that the users will ever be able to host or store all their content in a single location and directly share it from there, with others. One would usually have the most recently captured content on a mobile camera phone (or a digital still camera), and at some point later in time might move some of it to a home PC. Then, some of the photos might be uploaded to an on-line web service, while videos might be uploaded to another web service.

Thus, a solution for making the plethora of content repositories, devices and protocols look uniform, to the end users, would add value to their sharing activities. Based on that vision, this thesis introduces the concept of *Seamless Content Sharing*, which would allow users to share their content in a transparent and uniform way, even if it is distributed in multiple locations.

The most important aspect is the focus to user-centricity, meaning that users should be able to share their content with others, as simply as sending an e-mail. That is, **addressing people** and not devices, services or technologies. As the authors of [73] suggest, the ”killer application” for the Kodak Culture [19] will ”look and feel much like e-mail, but with a more robust underlying framework geared to photo sharing” and ”it would not require users to switch modes to view photos (as e-mails from current websites do), and it would retain the targeted, intentional nature of E-mail”. From the technology point of view, our publication [VII] tries to answer a similar research question: can we make a user-centric system in such a way that the sender would only need to indicate the person to receive the content (like in e-mail/MMS) and not the device or service to be used? This is what we call **Sharing with People**.

5.2 Use Cases

In this section brief use-cases that drive the Seamless Content Sharing concept are presented, as the scenarios that would need to be satisfied, in order to make user-generated content sharing more uniform and transparent.

5.2.1 Seamless Access to Any Content Repository

The elementary use case suggests that all the content repositories should be accessible in the same manner, by the end-user applications. For example, as shown in Fig. 25, Alice is able to access via the smart phone gallery application the content that is stored on the phone, at the home PC, or at any on-line service. The user experience could be exactly the same for all the repositories, presenting the content in a ”gallery-like” view. Vice versa, Alice is able to upload content to any one of

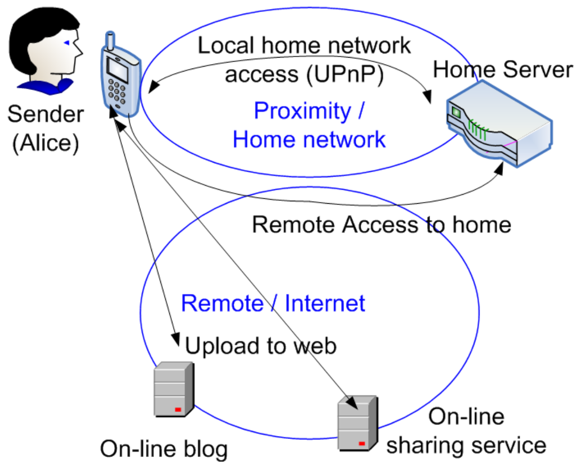

Fig. 25. *Seamless access to any content repository*

the available repositories, without the need to use different applications and perform domain specific actions.

5.2.2 User-Centric Content Sending/Giving

Sharing of content should be as simple as possible, from the user's point of view, in a user-centric manner. Sharing of content items is as simple as selecting the person(s), from the contacts list, to receive them. For example Alice picks a media item and selects "I want to share this with Bob".

The system should be "clever" enough to understand which are the best methods, technologies and devices to be used, for transferring the items to the recipient. As shown in Fig. 26, the transfer could happen in proximity (e.g. using Bluetooth or WLAN ad-hoc and UPnP) if the recipient's mobile device is near by. However if a suitable device of the receiving user is not in proximity (or if there is but it does not have the suitable networking bearers or content transfer protocols) an alternative transfer method should be found. In that case, the system could attempt to access the recipient's device remotely, for example over the cellular network, for delivering the content. It could also try to deliver the content to one of the home devices that the recipient might have, or via an on-line service. In other words, there would be no burden on the recipient or the sender to ensure the appropriate technology selection, so that the content arrives at its destination.

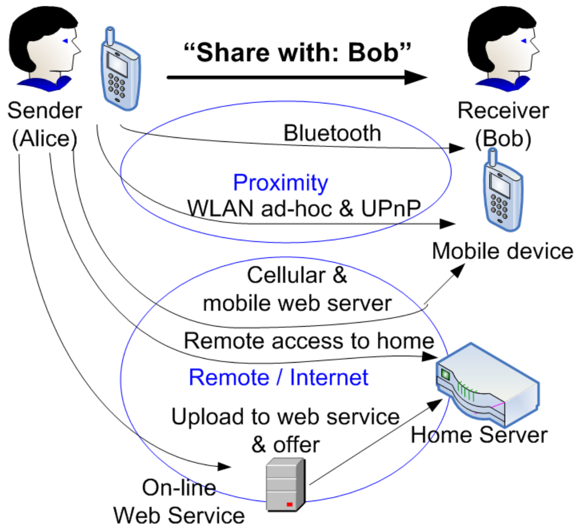

Fig. 26. *Examples of technologies/methods that could be used when sending content by selecting the recipient*

5.2.3 User-Centric Consumption of Offered Content

As mentioned earlier, we do not want to "force" the people to collect all their content in a single location or device, rather still allow them to use their preferred locations, at a given time. However, we believe that people should be able to offer their content, to others, without having to move it to a specific location. In addition to this, the people that get rights to access it should be unaware of the specific location, access method and technologies. Again, the system should be able to cover all the complexity and just allow content consumers to access the media offered to them, in a seamless and transparent way. As shown in Fig. 27, the content consumer should be able to browse offered content, by just selecting the name of the person that he is interested in. That could be a simple name selection from the device's contacts book application (e.g. "I want to see what Alice offers to me").

The system should be able to aggregate all the content, gathered from all the device and services that the offering person has and present it in a common interface to the consuming person. The user should not be bothered with entering technology details, user names, passwords and other configuration parameters.

As in the previous use case, the bearer and content access technologies to be used would be automatically selected, in the best possible way. Even if the best connectiv-

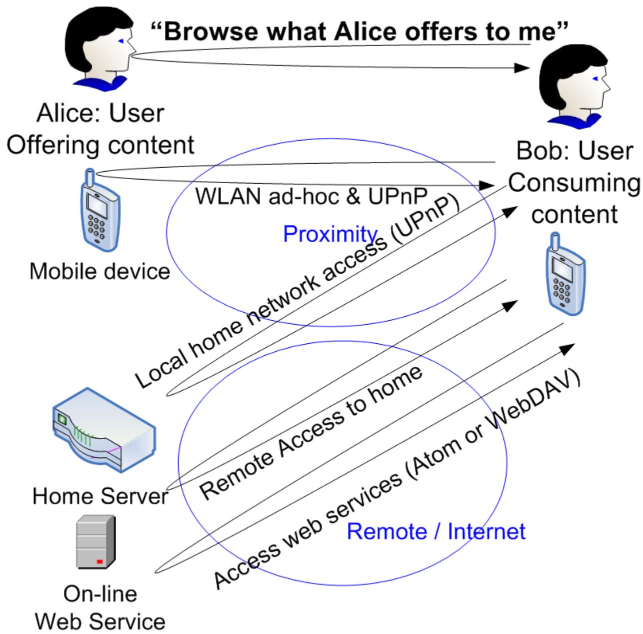

Fig. 27. *Consuming offered content from multiple devices/services*

ity method becomes unavailable, at some later point in time after the initial selection, an alternative should be found and transparently established, for ensuring seamless user experience.

5.2.4 Transparent Content Mobility

A more advanced use case, first introduced in [VII] is what we call *content mobility*. When it comes to media sharing, content mobility is defined as the transparent movement of, already offered, content to different devices or services, without the people, consuming it, noticing the movement.

An example is shown in Fig. 28, where a person offers some content that is available on a mobile device. Typically, that content could be an album containing the latest captured images and videos taken with a camera smart phone. A person that is allowed to consume this content can access it directly from the mobile device of the offering person, for example when they are in proximity. But, if at some later point in time the content owner decides to move this offered album to another location, as shown in the example diagram of Fig. 28 to a home server, the content would no

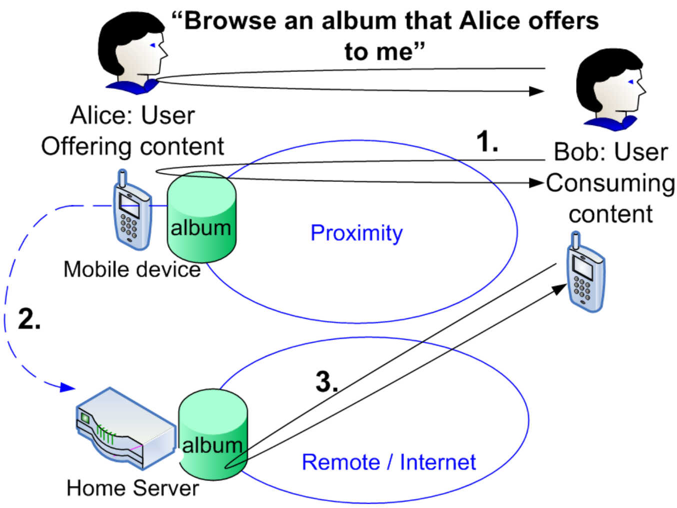

Fig. 28. *Concept of content mobility, in the context of sharing*

longer be available on the mobile device. In this scenario, the system should hide this content movement from the consuming person, in such a way that he can continue accessing the album, via remote access to the home server of the offering person, without noticing the content location change. Essentially, apart from change in the device offering the actual content, this content movement might also require change in the content access protocol used between the two devices (offering and consuming devices). This kind of scenario could also be realistic when people lose faith in an on-line sharing service and move their albums from there to another one, for example.

5.2.5 Group-Based Content Sharing

A group of people could share their content, which was co-created under the same environment or context, at a common location. For example, people attending the same wedding party might decide to pre-share their content, i.e. the content that everyone captures during this specific event, at a common location where everyone has access, later on. This scenario slightly disrupts the typical user-generated content life cycle (see 2.1), which suggests that sharing happens "post-capture" or at the end of the "at-capture" phase (see Fig.4). This use case allows the users to initiate their sharing action at the beginning of the "at-capture" phase, based on the context of their environment, namely depending on the location, event and people around them.

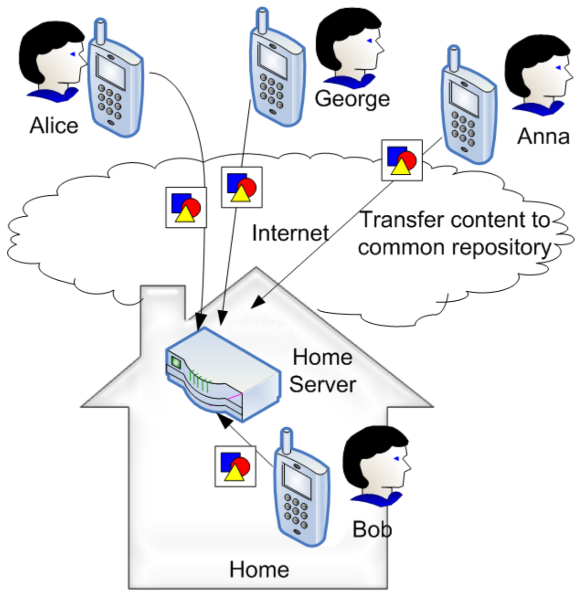

Fig. 29. *Group-based content sharing*

Fig. 29 shows such a use case where the content created by four different people is gathered on a common location, in this example being the home server of one of the users. Publication [VI] introduces an architecture and solution for this scenario.

5.2.6 Internet-Home Service Mash-up

Our final use case suggests that on-line services, hosted on the Internet, and home hosted services could be mashed-up in order to provide richer experiences to the end-users. Private and sensitive user-generated content could be securely hosted at the home infrastructure and selectively exposed to external services, when the user selects to do so, in a simple manner. For example, a family could host its calendar service on the home infrastructure (e.g. on a home server), where also the related content is stored. If an external service would like to get access to this data, it could be authorized to do so, by the home users. A realistic scenario could suggest that the user makes a trip booking via an on-line travel agency, which in turn would like to insert the relevant booking information to the family calendar. Or, an on-line super market store that would like to access, for example, the home hosted shopping list, in order to automate the daily household product purchasing process.

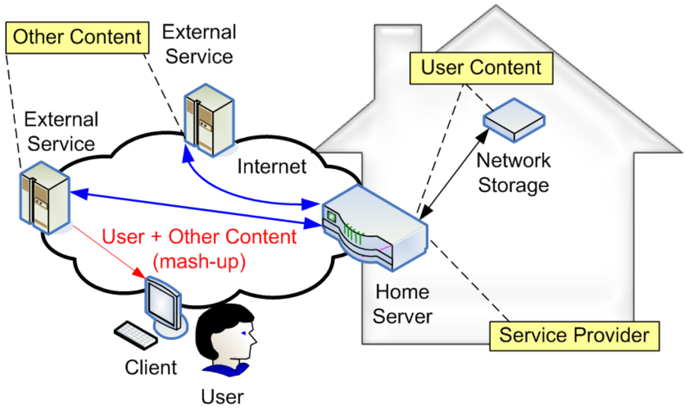

Fig. 30. *Internet-home service mash-up*

Fig. 30 illustrates the concept of these use cases, where the home hosted services and content can be mashed-up with external Internet services. A detailed model is analyzed and presented in [VIII], utilizing RESTful architecture.

5.3 Internet & Home Sharing Protocol Comparison

From the previously presented scenarios a strong correlation between on-line offered and home offered content is evident, as we want to treat sharing in those domains in a seamless manner. In section 3.3 we identified Atom and WebDAV as two of the important sharing protocols on the Internet and mobile domain, while in section 4.2.2 we showed that UPnP AV is the main content sharing protocol within the home domain. Targeting towards convergence of Internet, mobile and home domains, in the context of content sharing, would foremost mean identifying the commonalities of these sharing protocols. That is, studying how they relate to each other and if there can be an abstraction layer that can encompass them all. The work of publication [III] studied this, showing that those protocols have many similarities, as shown briefly in Table 3.

Our work in [III] shows that the similarities are more than the differences and thus a good enough common denominator exists, that would allow these sharing protocols to be treated via a common interface, on the user application layer. From the user interface point of view, the work of [63] describes a framework for accessing and controlling content distributed in home networks, interconnected homes, and in

Internet content sources, where tasks can be performed using a heterogeneous set of remote user interface devices. A RESTful approach is used, bringing this architectural style in the home domain.

Table 3. *Comparison of widely used sharing protocols*

	UPnP AV	Atom	WebDAV
Underlying protocol	HTTP	HTTP	HTTP
RESTful	No	Yes	Yes
User authentication	Not supported	HTTP auth	HTTP auth
Server/peer addressing	Dynamic (requires discovery)	Static (IP address / DNS name)	Static (IP address / DNS name)
Media files specified within	Content Item	Entry	Document
Collections of media files	Container	Feed	Collection
Nested collections	Yes	Limited	Yes
Metadata	Dublin Core & DIDL	XML similar to Dublin Core, extensible	XML based, extensible
Typically used in	home domain	on-line sharing services & blogs	remote file systems

5.4 Required Building Blocks

In order to enable the ultimate Seamless Content Sharing concept, where the scenarios of section 5.2 are satisfied, there is the need for some essential enablers and components, as shown in Fig. 31. In this section we will briefly point them out and link them to the publications created as part of this thesis research work.

For the home domain to be closely related and to possibly converge with the Internet and mobile domains we identified that enhanced remote access solutions are required, as those proposed by the work of [I] and [II], so that home services can be addressed

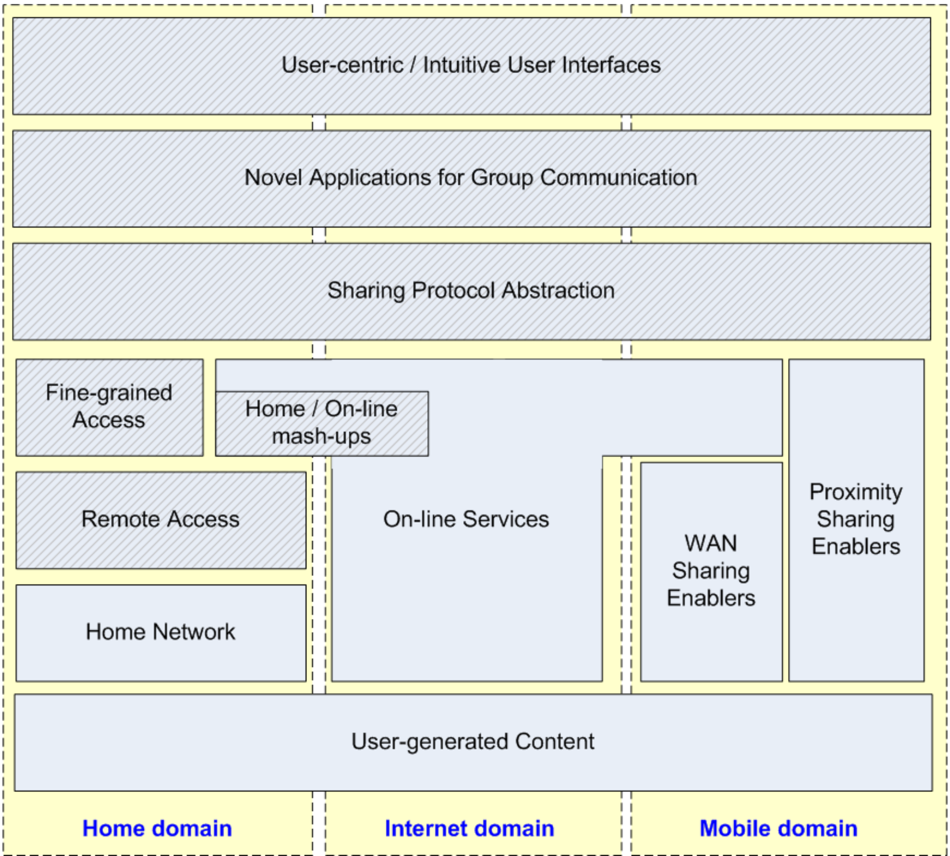

Fig. 31. *Building blocks & enablers required for seamless content sharing*

in a seamless manner regardless of the client's location and UPnP would be able to function outside the scope of a local network. Moreover, we identified that a mechanism for fine-grained access rights is currently missing from the home based content sharing and we presented a solution for that in [IV], where UPnP AV and Atom protocols are combined for exporting home hosted content in a web syndication feed format.

Moving further up, it was identified that an abstraction of sharing protocols is needed, and that could be possible via a generic sharing middleware, as the work of [III] suggested, for making mobile end-user applications sharing technology agnostic. This would create space for novel sharing applications that combine on-line sharing services, the mobile and the home, such as the advanced scenarios presented in [V] and [VI], for enhancing mobile blogging and group sharing, respectively.

Putting all these enablers in place the fundamental sharing habits and interaction between users and devices would change, creating a need for new user interfaces. This is tackled by [VII] where an enabling solution for making content sharing user-centric is presented, along with a study for a potentially new interaction method between the end user and the different content repositories.

Finally, the mashing-up home hosted content, even beyond typical multimedia content, with external services would be an important building block, for enhanced user control and privacy protection. This is tackled in the work of [VIII].

5.5 Summary

In this chapter the concept of seamless content sharing was presented, along with the five core use cases that drive the concept. The two important dimensions of the concept are the convergence of home, Internet and mobile domains, when it comes to content sharing protocols, and the user-centricity which allows content to be addressed to people, not devices or services. The important building blocks required for enabling seamless content sharing were presented and linked to the research work done in the scope of this thesis.

6. CONCLUSIONS

6.1 Generic Conclusions

In this thesis user-generated content sharing was studied, mainly from the technology point of view, in a holistic manner encompassing on-line sharing services, mobile sharing and the extended home. Digital capturing devices, especially affordable camera phones, brought digital images to the masses. At the same time, always-on, broadband, connectivity allows users to share their content with the family, friends, or wider community. But, there is a plethora of sharing methods and solutions, each with its benefits and disadvantages. As there is currently no ”winning” sharing solution, users are having multiple content repositories for satisfying their sharing needs, with content being distributed in multiple locations, services and devices.

One of the natural places to store content is the home and offering directly from there would sound as a promising scenario, especially since home networks are becoming commonplace in many countries with high penetration of broadband home connections. However, there are currently many challenges in making this possible, in a standard and interoperable way, as there are connectivity, security and privacy issues.

Trying to put the user in the center of all the scenarios and solutions, so that sharing becomes simpler and more efficient to use, this work targeted the convergence of the different domains in a seamless and transparent manner. We provided enablers that would make the people-to-people communication even more natural and the technologies ”life-tolerant” in order to be usable in daily life, even by novice and amateur users. The author hopes that all these enhancements could bring family and friends a bit closer, in sharing experiences, if applied in commercial products and services.

6.2 Main Results

The main research question that this work tried to answer was: can the user-generated content be seamlessly shared, no matter its physical location, among family and friends? The short answer is ”yes” and this is the core notion of the ”seamless content sharing” concept. As the sharing protocols used for content offering, in the on-line services, mobile and home domains have many similarities which can be abstracted in such a way that a sharing middleware could hide the protocol specific characteristics and provide generic sharing interfaces to the end-user applications. At the same time, applications could provide a unified interface towards the users, no matter the location of the content repositories. The Sharing with People solution introduced adds the user-centric dimension, so that people can share their content with others by addressing people (as simple as in e-mail), but with a powerful underlying system that finds the best matching device, service, access bearer and content sharing protocol to deliver the media to the recipient.

Moreover, the author believes that the digital home will play a key role in the future, as it can become the hub for family and friend content and experience sharing. Thus, key enablers that would make home an integral part of the Internet were studied, leading towards the ”Extended Home” concept where spatial and functional extensions of the core home network were considered. Two solutions for remote access to home networks were provided, as well as a solution that deals with the fine-grained access rights to home hosted content, bringing the UPnP AV protocols with the web syndication feed paradigm. The link of the home and 3rd party, semi-trusted, services is investigated, proving that rich mash-ups between the home and external services is possible, in a secure and privacy concerned manner.

Finally, the extended home, the on-line and mobile content sharing worlds converge so that not only the one provides solutions in the areas that the other is lacking, but they also compliment each other in a more holistic manner. Their combined functionalities and capabilities allow creation of services and experiences that were not possible before as the home provides the place for ultimate privacy, which is important when user-generated content is implicated, while on-line services provide the scalability and social extension required for sharing with the wider community.

6.3 Future Development

The author sees two directions towards where this research work could be further driven. Firstly, it was discussed that the devices and services should become ”clever” to make decisions regarding which is the best device, bearer, sharing protocol and service to be used, in order to share content with another user, based on his devices and availability. This advanced decision making could be further researched based on context ontologies and frameworks which would cover time, location, user, environment and device parameters, as decision input, while being expandable. The value of combining content sharing with context is that the system could become even more efficient and proactive, by mashing other sensor information, for helping the users share content with the appropriate people on the best possible way.

Secondly, researching user generated content beyond multimedia content, something that was briefly touched in [VIII], would be a very natural extension of this work. Families are generating in their home environment a lot of, non-multimedia, content that is not yet digitized, like shopping lists, calendars, schedules and to-do lists. Many of these need to be shared among the family members and it is currently done via simple pen and paper. What would it mean to have this, user-generated content, in digital format and what would be the sharing habits then, is a research question of its own.

7. AUTHOR'S CONTRIBUTION

The research work executed for this dissertation consists of 8 publications [I-VIII], all of which where done in a team environment, thus more than one people contributed to the work. However, based on our team culture and ethics, the main contributing person is identified by being the first author of these publications. In all of the included publications the author of this dissertation has been the main contributor, thus the first author. In this section, the research contribution of each publication will be pointed out, as well as the author's contribution to the respective work.

The logical flow of the publications is shown in Fig. 32, so that we start ”building” the seamless content sharing concept based on the basic enablers, such as remote access to home networks, content sharing middleware for mobile devices and novel sharing solutions, that bind the home and the mobile domains.

Publication I is a direct continuation of the authors work executed during his MSc thesis research [11], in the area of remote access to home networks, focusing on how in-home device and service addressing scheme can be independent of the client's location, that is either while in the home network or on a remote one (see ”Addressing scheme in/out home” in section 4.5.4). This work lead an initial evaluation of using Internet technologies (such as HTTP and DNS) in the internal home environment, providing a working prototype of the system that proved the feasibility. The author proposed the main solution (called HomeDNS), designed the system and implemented most of the prototype. The co-authors provided support on part of the implementation as well as ideas for extending the system functionality to other areas (such as a rendezvous point for SIP).

Publication II deals with the problem of remote access to home networks, focusing on transparently bridging a home UPnP network with a remote device, or network, without the need of any modifications on the end-user UPnP devices and applications. The author suggested the usage of the Atom publishing protocol as an alternative to the "problematic" SSDP (see "Compatibility with UPnP", in section 4.5.4) and proposed the appropriate mapping between the elements and functions of the two protocols. The co-author provided the valuable, in-depth, insight on the UPnP device architecture and suggested the modifications required to UPnP stack, for this enhancement.This work provided a holistic and realistic approach for solving the UPnP remote access problem and is expected to influence the related work of the UPnP Forum on this area.

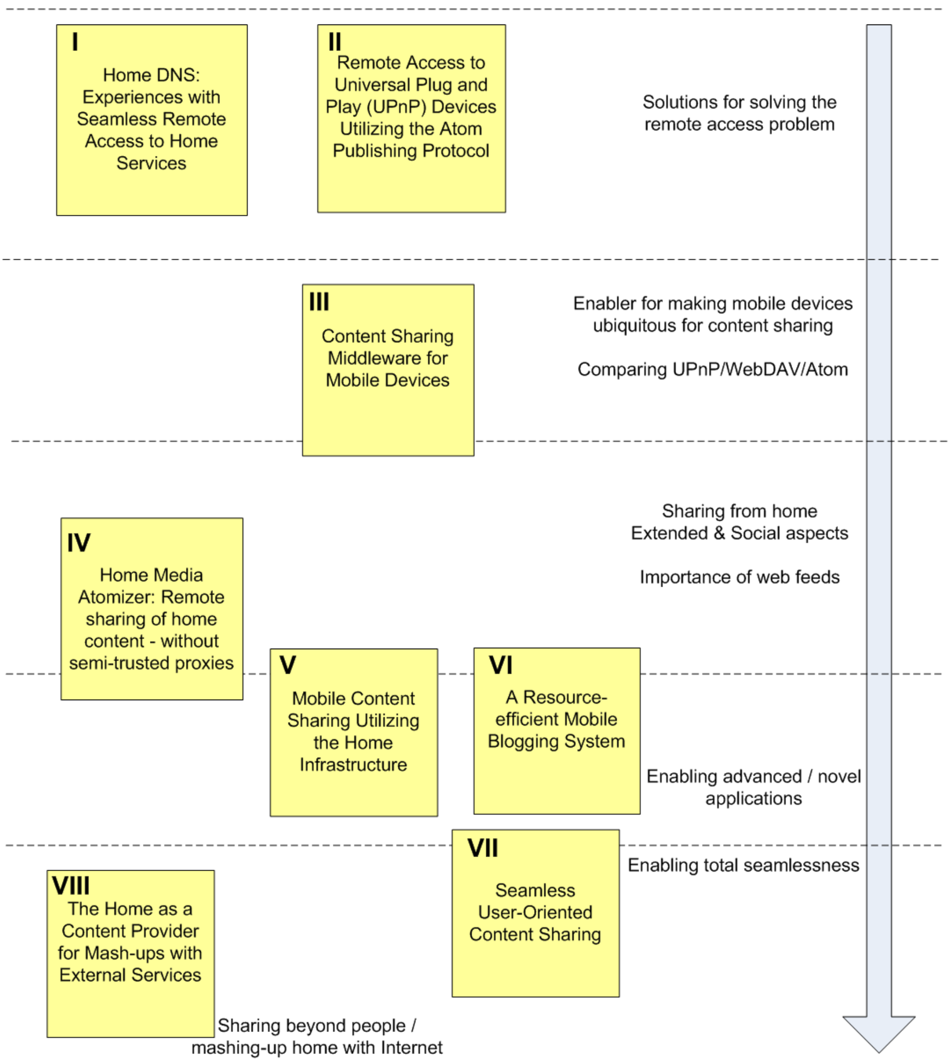

Fig. 32. Author's publications

Publication III introduced the first enabler towards unified content sharing, for mobile devices. After studying the commonalities of the three core content sharing and management protocols (namely Atom, WebDAV and UPnP), it introduced a middleware architecture for the S60 platform, along with a full implementation and performance measurements. The author contributed towards identifying the common and different characteristics of the studied sharing protocols and proposed a generic abstraction layer that could encompass all of them. The co-authors contributed towards the specification of the C++ interfaces and building blocks and drove the actual prototype implementation on the S60 platform. The author also contributed towards the performance measurements, along with the co-authors.

Publication IV introduced the concept of sharing content directly from home, not only among family members, but also among friends. The proposed solution allowed, via a UPnP to Atom proxy, fine-grained access rights to specific UPnP media folders, from mobile device whose users were either family members or friends, something that has been missing form other related solutions (see 4.6.2). The author contributed towards identifying the mapping of UPnP AV protocols to the Atom Syndication Format and the Atom Publishing protocols, specifying the interaction among the different components and the linkage between metadata. The co-authors contributed towards the certificate based authentication mechanism, as well as interfacing with the implementors of the solution, which was based on our specifications. Moreover, the author contributed towards extending (architecturally and with actual implementation enhancements) the ”core” solution to include the UPnP IGD functionality and support for having web runtime clients as content consumers.

Publication V introduced a novel solution for group based content sharing, that utilizes the home infrastructure as a sharing platform, instead of typical on-line services. The author motivated the need for the use case and prototyped the server-side implementation, based on the initial work of Publication IV. The co-authors designed and implemented the mobile phone client, based on the work originally delivered from Publication III and researched the related background work in the area.

Publication VI, which was chronologically the first of the publications (2006), presented an architecture that optimized the efficiency of mobile blogging (see 3.2.2), in an environment where the target audience of the blog is a small group of people (e.g. family and friends). The co-author provided his supervision and support for the executed work.

Publication VII paints the big picture, where seamless content sharing is becoming clear, since it connects the work of previous publications. It motivates the need for a user-centric sharing solution, that combines the home hosted, Internet hosted and in-proximity available user-generated content in a seamless experience. The author worked end-to-end on this solution, starting from the need for the specific use cases, defining the architecture and the protocols, prototyping the implementation and participating at the usability trial observations. The co-author lead the usability setup and interviews with the people that evaluated the system.

Publication VIII can be seen as the work that drives content sharing beyond the typical "sharing with family and friends", towards sharing with external entities, not users, home hosted content that could also be beyond typical multimedia content. This work opens the door towards making the home a part of the web 2.0 world, which would allow rich mash-ups of home hosted data with external semi-trusted services. The architecture makes sure that the content is securely hosted at home, but selectively exported, via secure web Application Programming Interface (API) authentication, to external service providers. The author introduced the model of mashing-up home and external data, in a web-style manner, and implemented the service broker prototype. The co-authors provided the implementation of the prototype home hosted service skeleton as well as their expertise on the security related issues.

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Publication I

P. Belimpasakis, A. Saaranen and R.Walsh, “Home DNS: Experiences with Seamless Remote Access to Home Services”

Publication II

P. Belimpasakis, V. Stirbu, “Remote Access to Universal Plug and Play (UPnP) Devices Utilizing the Atom Publishing Protocol”

Publication III

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Publication VIII

P. Belimpasakis, M-P. Michael, S. Moloney, "The Home as a Content Provider for Mash-ups with External Services"