Chapter 15
Infrastructures for Community Networks

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15.1 Introduction

Content delivery has undergone a sea of changes in recent years. While even only ten years back the major delivery channels were television and radio broadcast, nowadays content is delivered digitally via the Internet or other electronic delivery channels. The engineering problem of delivering multimedia content through the Internet has received much attention by the research community. However, the delivery of content to heterogeneous mobile terminals in a community context still poses many problems. Early Internet based content delivery systems were designed as centralized systems where content is provided from a central server to a large population of the end users (see Fig. 15.1-(a)). This trend is now shifting towards decentralized systems, such as Peer-to-Peer (P2P) systems, in which the role of the content provider and producer is no longer restricted to a few professional content creators. Thus, the content delivery paths is not anymore only from a central server through backbone networks to the end users, but also from one end user to other end user(s) (see Fig. 15.1-(b)). This has been triggered by the emergence of relatively cheap consumer electronics enabling everybody to become a content producer; and

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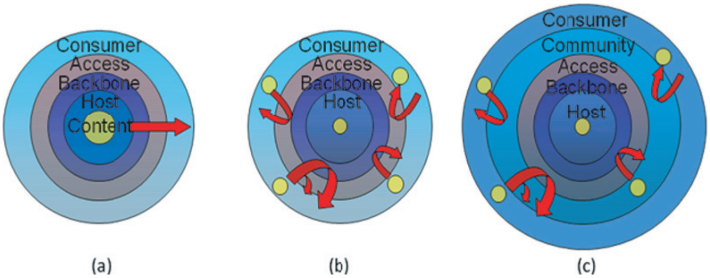

Fig. 15.1 Content delivery paths: (**a**) traditional, (**b**) today's P2P, (**c**) future community networks to the home (based on [44])

the high penetration of high-speed network access (e.g. xDSL networks) and P2P technologies turning computer users into content providers.

The European *Network-of-Excellence* CONTENT [65] studies future developments in this area with a specific focus on the resulting research challenges related to content delivery for and within community networks. Here, the end users not only consume content but also produce it and provide core elements of the network infrastructure, i.e. the physical community network. Thus, the content delivery path in community networks does not necessarily use any infrastructure provided by Internet Service Providers (ISPs) (see Fig. 15.1-(c)).

While the term "community network" is intuitively well understood it is worthwhile to analyze the concept of community networks. Rosson et al. define [54] community networks as follows:

"*A network community is a group of people whose communication and collaboration over networks strengthens and facilitates their shared identity and goals. The emergence of network communities is a striking example of what might be called grassroots technology development[..] A community network is a special case of a network community in which a physical community coextends with the network community.*"

According to this definition, the community is not only formed by people collaborating through the network, but also by people contributing with their own resources (like in civic and neighborhood networks). Community members mainly provide the access network in the form of several kinds of wireless network technologies, which are connected to the Internet via one or several ISPs. Since a (substantial) part of the content delivery in community networks can be done within the physical community networks without any ISP involvement, there is no evidence that communities might be a larger threat to the Internet than classical Content Delivery Network (CDN) and P2P users, quite the contrary.

With respect to the content delivery, the most important insight is that the "grassroots technology development" in community networks is driven by "people", i.e. the average end users, which might not have any particular education and skills in computer and network administration, software development etc. Thus, decentralization of content delivery must be combined with self-configuring, self-organizing, self-managing, and self-adapting solutions at all technical layers to minimize the need for human intervention.

Furthermore, Cowan et al. [20] identified in 1998 that content services play a central role:

"In fact, communities are repositories of large amounts of heterogeneous information that need to be searched, read, explored, acted upon, updated, and that offer opportunities for collaboration and other forms of two-way communication."

In 1998, multimedia content was not central to this insight. However, we argue that the technological developments in consumer electronics and Information Communication Technologies enable the easy use of multimedia content, and by this create a strong demand for various kinds of content services in community networks. Community members do not only want to consume content, but they want to share it, to search for particular content, to combine artifacts, and to edit complex multimedia objects.

Thus, content delivery and usage is special in the context of community networks for two major reasons: first, autonomic network and overlay solutions are needed to establish and maintain proper CDNs over physical community networks; and second, arbitrary and complex content services (e.g. content adaptation, transcoding, indexing, storage) are needed that go far beyond the simple transfer and consumption of content.

In order to describe the current state and short and long term research challenges, the reminder of this chapter is structured as follows: the following section gives background information on community networks, including a simple architectural framework and related work. The description of industrial challenges and long term research challenges follows this architectural framework. In the conclusions, the most important aspects of content delivery and content service for community networks are summarized.

15.2 Background and Related Work

An interesting phenomenon of the last few years is the creation of a number of Wireless Community Networks (WCNs) that provide Internet access in urban areas to community members. These networks were created either by the spontaneous collaboration of people who shared their own xDSL home connection to the Internet, or by the initiative of local institutions. For example, councils and universities have started to offer wireless access to Internet services to user communities (e.g. students) in limited areas (e.g. neighbourhoods, campuses, commercial halls) or public buildings. An example of "institutional" WCN is the Wireless Mesh Networks provided by the Town of Amherst [4] to its citizens.

The most popular "spontaneous" WCN is created by the so called "FON community" [25]. FON members (i.e. *Foneros*) share some of their home xDSL Internet connection and get free access to the Community's FON Spots worldwide. The FON community has also created a business, selling Internet access to those who decide not to share any connection with the rest of community. Up to now, FON is just acting as a WiFi ISP with just a peculiar business model. Some commercial Internet Service Providers in Europe have already raised concerns about legal issues related to the sharing of residential Internet access [41]. In the future, content services might be provided to the community and thereby increasing its business value. The idea of providing services to the community is already supported by the Ninux.org, an Italian community [43] that provides dynamic-DNS and a SIP-based PBX service to its members.

Interestingly enough, the spontaneous community network model has also proven to be successful in less developed countries, in particular to provide Internet connectivity in rural areas. The Dharamsala Wireless-Mesh community network came to life in February 2005, following the deregulation for outdoor use of WiFi in India. Now the network provides broadband Internet services to a few thousands users. Apart from Internet access, community members use the network for file-sharing applications, off-site backups, playback of high quality video from remote archives and extensive VoIP telephony.

To meet today's and future challenges of content delivery and usage in community networks, it is not sufficient to address individual sub-systems only, like only the CDN. Instead, the entire system, comprising IP based networks, CDNs, content services, and end users must be covered.

15.2.1 Architectural Framework

In the architectural framework depicted in Fig. 15.2, community networks are expected to play a central role in the intermediate future since they provide basic connectivity. In this context, physical community networks are the sum of all the networks that interconnect devices within home environments, neighborhoods, and their combination into multi-hop and mesh networks. Comparable to social networks the primary aim of community networks is to support the local community. Since multimedia content is usually distributed over such networks, several new appealing research issues come up, as for example, mobility, nomadicity, resource assignment, user required/perceived Quality of Service (QoS) and Quality of Experience (QoE), topological robustness, resilience, and network protection.

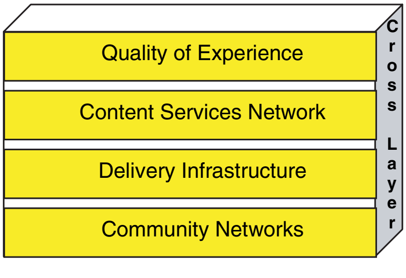

Fig. 15.2 High level architectural framework

Typically, overlay network solutions are used to implement CDNs, which is captured in our architectural framework by the delivery infrastructure level. They include more and more end users as well, visible as peers and overlay nodes that provide certain resources and services to the network. Overlay networks provide an abstraction that hides the irksome details in the underlying physical networks, e.g. of a wireless mesh network that forms a community network. However, overlay network solutions must also be aware of the basic properties of the underlying community networks to fulfill the non-functional requirements of services, such as resilience and performance. Typical functional aspects of overlays are caching and request routing. They can be solved through networks of proxy caches or distributed hash tables that interconnect peers directly.

On top of the delivery infrastructures, content services networks consist of a set of services for handling multimedia content. These services should support the entire life-cycle of audiovisual content and should also be able to interoperate to create complex services through the combination of several simpler ones. Typical examples of content services are automatic analysis and indexing services for content classification and content abstraction, transcoding services for format adaptation, as well as search services providing sophisticate support for content search.

Finally, on top of the architectural framework is the QoE level, which reflects the actual experience of the end user. In general, QoS is defined as a set of technical parameters capturing mainly quantitative aspects such as throughput, error rate, delay, jitter, frames per second, and bits per pixel. The lower levels of the architectural framework cover networking aware QoS parameters. However, these QoS parameters do not actually reflect the user experience, which depends not only on technical parameters, but also on the effects that failures and faults have on the actual perceived quality. Although QoE is a function of different QoS parameters at network, system and application level, there is not a direct translation between QoS parameters and QoE. Therefore, it has to be established which kind of degradation actually lowers the user experience the least.

Orthogonal to these basic four levels of the architectural framework there are several cross layer issues which are relevant for the scenario of content delivery in community networks. One important class of these cross layer issues is related to QoS parameters at different levels and how they relate and correlate to each other. Another class of cross layer issues is related to the problem that functions at different layers might impact each other, which could in the case of self-adapting solutions lead to cascading effects or unstable system behavior.

15.2.2 Community Networks

Community networks are generally networking infrastructures not owned by ISPs but by individual users or groups of users sharing resources distributed in a relatively small geographical area, like a neighborhood. Providing connectivity to community networks is a challenging task since nodes use a diversity of access technologies and can display a degree of mobility.

Current technologies which may be used for community network infrastructure are: xDSL, Powerline, FTTH for fixed nodes connected to an ISP; WiMAX, MBWA, 3G/UMTS/HSDPA for nodes with wireless access to an ISP; WiFi and Bluetooth for mobile nodes and home networks. Due to the availability of such a large variety of networking technologies, community networks may include nodes not only acting as user terminals, but also as routers, relays, or gateways. Fixed nodes, for instance, may behave as hot-spots, whilst visiting nodes, i.e. devices traveling through the area of the community network, may behave as a mobile gateway, router or terminal.

Within the concept of community networking, multiple networking technologies come together such as mobility with Mobile IPv4 and IPv6, multihoming, network mobility (NEMO), mobile ad-hoc networks (MANETs), wireless mesh networks (WMNs), and even wireless sensor networks (WSNs) and wireless multimedia sensor networks (WMSN). Usually, this interworking of different networking technologies is not pre-planned nor is it managed by operators. Hence, self-configuration capabilities as addressed by autonomic networks are required. In summary, community networks exploit a wide range of network technologies and techniques resulting in a challenging research environment.

The community networking scenario adds extra complexity to the handover process since in addition to handover within the same technology (i.e. *horizontal handover*) the handover between different networking technologies (i.e. *vertical handover*) also has to be supported. In order to efficiently manage such heterogeneous environments, the IEEE 802.21 standard is currently being developed within IEEE. This standard aims at enabling handover and interoperability between heterogeneous network types, including 802 and non-802 networks. The 802.21 standard defines an abstraction layer, providing Media Independent Handover (MIH) functions with the goal of simplifying the management of handovers to and from different access technologies.

As the distribution of multimedia content includes real-time delivery, QoS becomes a key aspect in community networks. QoS provision is still an open issue in wired networks, but it is even more complex in wireless environments. In this context, the evolution of the IEEE 802.11 extensions to provide QoS is crucial for the deployment of Multimedia Wireless. Also, contributions for QoS in MANETs and WMNs are of utmost importance for content delivery in community networks.

15.2.3 Delivery Infrastructures

Delivery infrastructure in the context of this chapter refers to a logical infrastructure created on top of a community network with the specific purpose of enabling access to content services. Most of today's delivery infrastructures mainly aim at the efficient delivery of content to community members. To overcome the limitations of the traditional client/server approach, the P2P paradigm is becoming more and more popular. P2P infrastructures usually implement some form of overlay network to deploy services that cannot be directly embedded in the underlying network, e.g. multicast routing object location, and event propagation.

Typical supporting services implemented by means of overlays are for instance request routing and actual content delivery. These services can either be implemented with the collaboration of end systems alone, or with support of specialized proxies.

A common theme in the research of delivery infrastructures for community networks is *autonomicity*. Community networks are largely based on collaborating individuals that provide resources to the community network. Therefore, P2P technologies are very important not only in the case of downloading and streaming of stored content, but also for live streaming and every other aspect of resource sharing.

Considering the key building blocks of the widely deployed P2P based CDNs, three basic elements can be distinguished, viz. the *peer-to-peer overlay network*, a specific *content delivery strategy*, and a *caching strategy*. The overlay network is responsible for connecting the participating peers, management of joining and leaving peers, and routing of queries and other messages. The content delivery strategy is responsible for delivering the required content from the source to its destination. The last strategy increases the availability of the content in the P2P system and its efficiency.

The enormous potential and advantages of decentralized infrastructures has already become apparent in the days of Napster. Since then, significant research efforts have been invested in designing self-organized, scalable, robust, and efficient overlay networks. However, it is crucial to note that the performance of a P2P overlay depends on various factors (e.g. application, resources of participating peers, and user behavior) that are less relevant in centralized systems. For example, a specific overlay design can perform well in the case of low churn rate whereas in the case of high churn its performance may decrease to average. Furthermore, content delivery systems pose certain requirements on overlay networks, like finding users that are sharing the demanded files, incentive mechanisms, or enabling efficient inter-peer communication at low costs. Thus, there are many research initiatives to study the direct or indirect influences and dependencies between P2P overlay networks and the underlined networking strategies in a content delivery system.

Considering content delivery strategies, many aspects have to be taken into account separately alongside of interdependencies that might exist. Their influence is crucial for the overall efficiency and performance of a content delivery system. One of the most important aspects is choosing a scheduling strategy for the files to be transmitted. Download strategies as the one used by BitTorrent or network coding are proven to be very efficient for long and large scale downloading sessions [26, 27]. However, with the current trend of content delivery technology, such as Podcasting, new challenges are arising. Therefore, it is necessary to investigate if the aforementioned state-of-the-art strategies are still appropriate, given the requirements of emerging content sharing and delivery strategies.

Not only file sharing, but also the use of live streaming applications is growing fast in community environments. These applications and many others relying on continuous data flows, from IPTV to massive multiplayer online games, have special needs. They are delay sensitive, need group communication and QoS support. Many solutions have been proposed, but none has been adopted on a wider scale. Nowadays, protocols designed for continuous data flows do not rely exclusively on the classical client/server model, but can also organize the receivers into an overlay network, where they are supposed to collaborate with each other following the P2P paradigm.

Many recent proposals related to Live Audio/Video Streaming using P2P overlays are derived from initial work that extended application-level multicast to the end systems [17]. The first generation control-driven approach focuses on building an initial overlay corresponding to the control plane and is usually implemented as a mesh or a tree. A second overlay, usually a spanning tree, is then created and managed for the actual data transmission. Peercast [12] is the most famous example with a popular implementation and a large audience. A lot of work has been carried out to improve the control plane in order to cope with the high dynamics of the P2P overlay. For example, Nice is using a sophisticated clustering scheme [8]. More recent work tries to improve robustness using a hybrid tree/structure. An example for this is Bullet [31]. A new generation, data-driven approach stresses the need to cope directly with data. Peers exchange data availability and then they choose their neighborhood according to the data they need [8]. Further, epidemic algorithms are currently being proposed in systems such as Donet [63] to improve the data delivery. P2P Live Streaming is already reality. However, so far little has been done to demonstrate their efficiency on a very large scale. Simulation is one way to validate the feasibility of such dynamic infrastructures [50]. An alternative approach is to study proprietary applications in real testbeds, like PlanetLab [46]. The largest P2P Live Streaming deployments are related to IPTV applications and are only associated to proprietary protocols and architectures [41, 47, 48, 53, 56, 57, 58]. Thus, only their behavior but not the protocols itself can be analyzed.

The behavior of peers in a community network plays a key role. At the one end of the scale are altruistic peers that provide resources without expecting any return. At the other end there are so called "free riders" who only consume but do not provide any resources, which is a rational behavior in systems without any sharing incentives. Therefore, it has become clear that some kind of incentive scheme is necessary to achieve an optimal utilization of system resources in a system context as well as for individual peers. This is currently an active research area.

15.2.4 Content Services Networks

On top of the delivery infrastructure resides the content services network. A content services network is an infrastructure that provides a whole range of services to optimize the content experience. Users might be able to access such services for easier navigation, and personalized adaptation of content to their needs. In fact, the idea is to use so called content services in conjunction with the underlying network infrastructure to provide a network of content services and by doing so, create a content network. Content services network subsumes a number of sub-areas that can be grouped into:

- **Content Services Network Architecture and Services Framework** comprising issues related to the underlying architectural model for content service networks.
- **Service Interaction** encompassing all issues related to service integration and usage in general, such as service discovery, service description, service quality, service level agreement, etc.
- **Service Instances** include specific content services that improve the delivery and user experience in content service networks.

The aim of building a content services network is to integrate, in an open way, tools and mechanisms that enable the creation and re-purposing of assets for the benefit of the communities of users as well as allowing commercial use by innovative companies. In order to achieve this, a suitable model and architecture that allows to easily "plug" such content services into the services network is necessary. Recently, the concept of Service Oriented Architecture (SOA) has been introduced to achieve optimal support for business processes through the underlying IT architecture [13]. The main benefits of a SOA are reusable components that can be easily organized to build flexible and modular applications. Therefore it seems to be an appropriate abstraction for content services networks. At present, the SOA paradigm is mostly realized using Web Services [7].

Two major research issues within a service based content network architecture are related to *service interaction*, i.e. the way services are described and the way appropriate services are discovered. *Service description* is a fundamental issue for ensuring easy user access and a simple management of services. Examples of standards in this area are for instance those defined by the W3C for the Semantic Web [2]. Several formalisms have been proposed, at various expressivity levels, from simple semantic mark-up syntaxes (e.g. RDF [36]) to ontologies (e.g. OWL [19]). An OWL-based Web Service Ontology, OWL-S, has been proposed specifically for Web services, in order to describe their properties unambiguously [37]. A recent initiative defined a *Semantic Web Services Framework* (SWSF) [11], which includes the *Semantic Web Services Language*. There is considerable ongoing work in the area of *service discovery*. Both, UDDI [59] and the ebXML registry [24], for example, support finding services by name, type, and binding according to a taxonomy. Another specification effort is WS-Dynamic Discovery [38], a local area network service discovery mechanism for discovering Web services by using local-scoped multicast.

Service instances represent the value added services that are provided within (or at the edge) the communication infrastructure for tailored and adapted content delivery. Many different kinds of services can be envisaged in this context; for example, content adaptation service and QoE. Issues related to content adaptation have been addressed for some time. For instance, Smith, Mohan and Li have presented research dealing with ad-hoc adaptation for heterogeneous terminals. Their work has focused on the definition of techniques for content representation, among which the so-called InfoPyramid [39] plays a major role. Lemlouma and Layaida present in their work a novel technique for content negotiation [34]. They introduce the Negotiation and Adaptation Core (NAC), a basic system for negotiating and adapting multimedia services to heterogeneous terminals. Lum and Lau highlight in [35] the need for content adaptation and propose to use a Decision Engine as the logical entity in charge of taking decisions on how to adapt a specific content to client's presentation capabilities. Boll, Klas and Wandel propose in [15] a three-stage adaptation strategy, based on Augmentation, i.e. pre-adaptation during which alternative versions of a content are realized; Static Adaptation, i.e. deletion of the non-relevant alternatives; and Dynamic Adaptation, i.e. choice of the most appropriate alternative among those who survived the previous phase.

Previous research efforts towards the assessment of the end user perceived quality are mostly adequate for MPEG-2 videos only. They are based on either objective or subjective procedures. Subjective approaches assume human experience as the only grading factor, i.e. QoE. Objective procedures are performed without human intervention and give more stable results, but do not necessarily reflect the user quality perception. Examples of objective metrics are PSNR, MAE, MSE, and RMSE [52, 60, 61]. The methods for assessing the perceived video quality objectively do not usually take the Human Visual Senses (HVS) sufficiently into account. The human senses cover many errors quite effectively. Thus, objective measurements may not reflect the user perceived quality. Other methods that also consider HVS are therefore required (see [33, 62, 64]). The goal of this work is to provide QoE assessment as a service within the Content Services Infrastructure.

15.3 Visionary Thoughts for Practitioners

Industry related and short term research challenges are, in contrast to the long-term research challenges, less speculative and more focused on what can be realized within the coming years. In the following, different aspects in the context of the identified architectural areas are being discussed.

15.3.1 Community Networks

Mobility has been a research topic during the last years and solutions focused on different layers of the OSI stack have been explored. Specifically, the IETF has standardized mobility solutions at the IP layer, i.e. Mobile IPv4 [45] and Mobile IPv6 [29]. In addition, it has standardized three extensions to Mobile IPv6: Fast Handovers [30], Hierarchical Mobile IPv6 [51], and Network Mobility [22].

It has been shown in a number of studies [5, 6] that maintaining the connection while the device is moving is still a big challenge. In addition, these protocols do not explicitly support heterogeneous networking environments. Achieving seamless handover in a heterogeneous environment presents many challenges especially when considering multihoming. Multihoming [28] is a technique where the main objective is to increase reliability of Internet connections for networks or single nodes. This technique uses multiple interfaces connected to different ISPs. In this way, a multihomed node has different paths available for communication. Many research papers [18, 42, 49] have been published exploiting the benefits of multihoming in static nodes or networks. However, using multihoming in mobile and heterogeneous networking is a relatively new research topic that presents many challenges.

The IEEE 802.21 [23] is a recent effort of the IEEE that aims at enabling handover and interoperability between heterogeneous network types including both 802 and non-802 networks. The IEEE 802.11e task group has refined the 802.11 MAC to provide audio and video applications with QoS guarantees [9]. The recently approved version of IEEE 802.11e introduces an improvement on the DCF algorithm aiming to distinguish traffic categories.

Due to the distributed nature of IEEE 802.11 DCF, the protocol under review is also used for the case of multi-hop communication [14, 16]. Currently, the area of ad hoc and mesh networks [3, 10] enjoys the attention of a significant portion of the scientific community. Communication via multiple hops is closely linked with the problem of routing and is still a hot research topic. Here the knowledge of the available bandwidth in a given area is one of the key factors since most of these routing protocols support QoS based on the bandwidth available within an area.

Finally, in such an open scenario where network management and device's configuration relays on the users misbehavior detection and traffic anomaly detection, security threats such as Distributed Denial of Service (DDoS) attacks should be considered as a critical aspect. Misbehavior detection is especially important in WMN at MAC level while traffic anomaly detection covers the whole CDN.

15.3.2 Delivery Infrastructures

The current challenge to improve P2P-based content delivery infrastructures consists in creating overlays that are better suited to the particular requirements of content services.

Delivery of traditional Web content to user communities may benefit from the possibility of clustering clients according to their network location. One such clustering may be helpful for efficiently moving content replicas or proxy caches towards those parts of the network where clients are more densely distributed. A research proposal for real-time Web clients clustering appeared in [32] and it is based on client IP addresses extraction from the Web server logs and clustering of addresses based on BGP routing information. One such approach may only be pursued in traditional CDNs, where the content provider and the CDN service provider closely cooperate to serve the content provider's objective of optimal content delivery.

The P2P model has been recently applied to Voice over Internet Protocol (VoIP) applications, such as Skype, proving its usefulness for both searching users location and relaying voice packets. Selecting one or multiple suitable peers to relay voice packets is a critical factor for the quality, scalability, and cost of a VoIP system. However, Ren et al. [53] show that the network probing activity, required for peer selection, may affect the scalability of the whole application and its performance. To reduce the network overhead imposed by several uncorrelated P2P overlays, Nakao et al. [40] propose to establish some basic services into the network (*underlay*) to properly and efficiently support the creation of concurrent application-specific overlays.

Another challenge proposed by P2P applications is the tendency of the huge traffic they produce to "escape" the Traffic Engineering efforts of ISPs [55]. Recently it has been proposed [1] to try and pursue some form of cooperation between P2P applications and ISPs, in order to find a common benefit.

Finally, today's solutions for classical content delivery infrastructures are well designed considering the topology or the wide area network in which they serve. However, they are restricted in the sense that they are not concerned with the last mile to the client and the end user community infrastructures. They regard the last mile just as a link to the client and do not consider the topology of the network connecting the client to the content delivery infrastructure. The recent trends in technology clearly indicate that neighborhood networks and home networks will connect clients to the core CDN. The adaptation of the delivery path also in the neighborhood and end user networks and its proper integration with the wide-area distribution infrastructure is a problem that has yet to be systematically addressed. Combinations of P2P and classical CDNs seem to be one good starting point. Early work on this topic is presented by Cowan et al. [20].

15.3.3 Content Services Network

Content services that are available to typical community network members are mainly concerned with the consumption of audiovisual content, like RealPlayer and Windows Media player. Furthermore, content provisioning is possible through Web based services and streaming services. However, services and applications that are related to the creation and re-purposing of content, including management and editing are not available. Thus, the service offering is currently limited to the provision and consumption of media. Further, there is also little freedom for users to add their own content and create their own communities. Examples such as YouTube and MySpace show that there is a desire for sharing information and content between users. However, in contrast to these examples, in community networks there is a target "audience", i.e. the members of the community.

This implies that on the one hand there is a need for new services that give users more freedom in the way they interact and share content. On the other hand, there should be more services that allow users to create (new) content, set-up their own communities, and control their environment. This goes beyond the existing model (such as FlickR) where users are basically only able to manage and share the content. In this new model, they would also be able to determine (to a certain extent) how content is delivered (e.g. over a video streaming service), what to do in case of insufficient resources (i.e. what kind of adaptation strategy should be applied), and even what kind of incentive mechanisms should be used. Thus, there should be two different basic service types, viz. the more traditional content services and the content and infrastructure support services. Especially the latter is not sufficiently provided at this moment.

In order to be open and compatible, in this context, it is important to have a service framework that allows different service providers to offer their content or support services. Inspired by the idea behind Web services, a proper content services network architecture needs to be developed so that it provides a framework in which all the different services for optimized delivery and content usage can be placed. This effectively provides an opportunity for commercial and private service providers to offer services in the longer term, within a community content network environment. Such a content service network framework effectively creates a market place for services alongside a more community oriented service provisioning. In order to achieve this fully, the open research questions in the next section have to be addressed first.

15.4 Future Research Directions

In this section, the long term research challenges and some of the research directions that are followed by the CONTENT Network-of-Excellence to address these challenges are presented.

15.4.1 Community Networks

Today's research in content delivery related communication is, for instance, dealing with streaming, network caching, QoS, and P2P issues. These are well developed research areas with an established set of researchers addressing different parts of the problem space. For community-based content networks, WMN are becoming more and more important since they can be deployed without having to invest in an expensive wired infrastructure. However, there are still a number of research issues to be addressed in this context, e.g. regarding link quality, channel assignment and routing, gateway selection, etc. These have to be investigated before WMN can be a fully integral part of content networks. It is envisaged that integrated multihomed networks will be functional by the end of the decade, based on the research progress in WMN, network selection and other related research open issues.

In order to provide seamless communication, an *End-to-End (E2E) infrastructure* is required. This infrastructure will integrate different network types under a unifying architecture dealing with aspects such as E2E QoS provision, E2E QoS routing, and traffic engineering. Another research strand is dealing with misbehavior detection and the protection of content networks from attacks. This research is going to result in *misbehavior-sensitive networks* that provide resilience mechanisms for the detection and protection of the network. A further, parallel development is the *autonomous distribution* of content. This includes autonomic communication architectures based on P2P principles. Issues here are related to the delivery, like P2P streaming, but also to trust, co-ordination and management aspects. Autonomic content delivery will also include certain service aspects (see below). Highly *interactive* applications within community content networks are still a major challenge. By the next decade we envisage that highly heterogeneous infrastructures based on different network types will be able to cope with this and provide the necessary support.

15.4.2 Delivery Infrastructures

The core challenge for future delivery and service infrastructures for community networks is to develop autonomic *Content Networks* (CNs) that integrate autonomic overlay structures and content services, like content management. CNs will improve the reliability and efficiency of traditional CDNs and reduce their management overhead. Furthermore, CNs will also extend the application spectrum of traditional solutions by, for instance, transparently supporting streaming media to mobile users, providing interactive multimedia applications, or adapting them to a community networking scenario. Research in this context requires dealing with the design of a novel architecture for autonomic CNs, including novel methods for linking content management with content delivery, and new protocols for the efficient transport of control information. Research issues that need to be addressed here are related to the actual delivery, but also how to appropriately orchestrate content management, services functions, and communications. The latter can be achieved using cross-layer information flow to better coordinate the different parts.

Current efforts are often only focused on a particular application domain, like VoD, IPTV, or Web browsing, and targeted towards fairly rigid dissemination structures. In contrast, future P2P technologies need to be adaptive and follow a more flexible approach than the rather constrained approaches in the context of a traditional CDN.

How to capture the systems aspects of the related processes and how to facilitate these developments through an appropriate architectural model have not been sufficiently investigated. Important in this context is that the content delivery infrastructure and the content management functionality are well synchronized. In order to achieve this, the area of cross-layer interaction plays a key role. This includes functional and interface work on interaction between the different layers of the communications architecture in order to facilitate the development and implementation of emerging ubiquitous content networks as well as enabling content management environments that allow faster production and easier access.

Future research needs to expedite the convergence of content production and delivery, and bridge the technological gap between the two areas. As a consequence new possibilities for content creation, programme formats, and end-to-end content delivery within one framework are becoming possible.

One of the guiding principles to improve content delivery is adaptation to network conditions. If designed correctly, adaptation can lead to a much better system utilization and efficiency. However, using adaptation in two sub-systems that are independent of each other, i.e. using self-organizing cooperative caching schemes on top of adaptive overlays without any further precaution, can result in a situation where the adaptation at one level thwarts the adaptation carried out in the other system part. Furthermore, the conditions that can trigger adaptation consider only data that is derived through network measurements. Therefore, cross layer issues represent a particular challenge in this context.

15.4.3 Content Services Networks

While more advanced and better content services are needed for the future, it is also important to structure them in a way that allows to combine existing service instances to more complex services. Different service providers can offer services ranging from infrastructure support to actual content provision. The former, for example, can include a service providing a live video streaming infrastructure according to a specified Service Level Agreement (SLA). This service in turn can make use of other infrastructure services (e.g. a QoE assessment service). A user or community group could rent such a service for the distribution of their content and effectively create a content delivery service on top of it.

In order to establish such a framework the supporting concepts and underlying architecture have to be well specified while still leaving room for flexible service provisioning. The services within such a framework themselves form a content services network with each service providing a distinct, self-contained service function. Services can be distributed throughout the infrastructure and form a mesh of coordinated mechanisms using either standard service interfaces for their coordination or service specific protocols. The role of the content service architect is to allow different services to be placed into the overall service framework and make them part of the content network infrastructure. Services in this context range from *infrastructure services* (e.g. QoS and QoE assessment) over *delivery support services* (such as transcoding and content adaptation), to *content centric services* (e.g. video summarization and indexing).

The service architecture follows a generic Service Oriented Architecture (SOA) model. The service model provides a generic service specification that deals with aspects all content services have to conform to. This description leaves sufficient scope for individual services to provide their own specification detailing the full service interface and functionality. A content service has to provide a set of interfaces through which it communicates with other services or applications. The internal organization and service structure is not part of this model, neither is the service specific interface description or service specific functionality specification.

A service can be stateful or stateless. Stateful services have to provide an interface to the service user to query the state of its execution. It should also be possible to enter into an agreement about the provisioning of QoS. This requires the specification of an SLA. The SLA itself is service specific and its format needs to be specified in the service description. Context awareness refers to the services that take information from the application or environmental context to control and manage the service. Through cross-layer interaction the service retrieves information from underlying layers and system components. Through this it becomes more aware of the system environment and can either adapt or try to influence the underlying components. User interaction allows the specification of preferences by the user in order to adapt the service to user needs. Figure 15.3 shows the generic content service model.

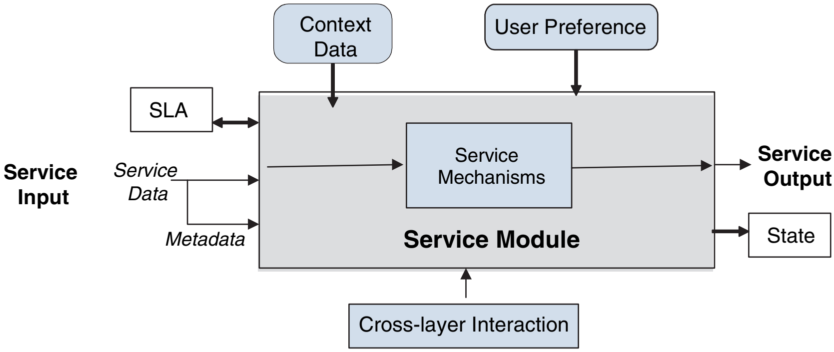

Fig. 15.3 Content service model

The content service framework provides the context within which the services are placed. Crucial in the context of the service framework is the service description and its representation within the service registry. Services can use other services through this service registry via standard interfaces. Such an approach allows dynamic and automatic composition of content services and opens up new business opportunities for brokerage services.

15.4.4 Cross Layer Issues

It is generally accepted in the research community that besides their advantages, layered system architectures have also clear disadvantages. In order to enable resource aware distributed applications, access to network layer information is necessary. Cross layered approaches are used to achieve this kind of awareness beyond layer interfaces, but they are designed for particular solutions. Thus, understanding and developing a better architectural solution than strict layering is an important research challenge in general. However, cross layer issues are especially important in the context of future CNs for community networks since autonomic solutions, like self-adapting functions, need to be applied. As mentioned earlier, independent adaptation of different functions might influence each other since they share resources. For instance, both might have an impact on network traffic. The first step towards addressing this challenge is to identify a set of metrics for each layer, including QoS parameters and resource consumption parameters and to model their dependencies between the layers. This first step seems trivial, but to carry it out successfully, this set of metrics and their definitions need to be accepted and used by the entire research community working in this area. Nowadays, many different and incompatible metrics and definitions are used. Modeling the dependency among parameters needs also to include the understanding of the functional behavior of the system elements. To provide the proper tools for this challenge, the CONTENT Network-of-Excellence investigates the development of a generic benchmarking suite for CNs following a modular approach in which the different levels of a CN might be considered as the system under test and the other levels represent the environment and the workload.

15.5 The CONTENT Approach

The CONTENT architectural framework does not provide a blueprint for the implementation of community based content networks, it much rather provides guidelines and develops basic principles according to which such networks can be developed. In order to validate the proposed principles and mechanisms within the framework a number of aspects are currently being assessed. The strategy hereby is to implement key elements and assess their performance through measurements and simulations. This is carried out in the context of the three architectural layers, or in the case of cross layer activities, related to inter-layer aspects. We illustrate this in the following with three sample research activities and results in CONTENT.

At the community network level, simulation and measurement in a real testbed is being used for studying performance and QoS in the case of mobile terminals performing both vertical and horizontal handovers. Also simulation is used to validate new proposals for available bandwidth estimation in wireless networks. Finally, measurements in real testbeds are being made to analyze and define the appropriate metrics for QoS at network level and other metrics which may be useful for upper layers. As a sample of the preliminary results obtained, Fig. 15.4 shows a comparison of the instantaneous available bandwidth estimation in a community network using both the *pathChirp* tool and our proposal. The proposal under study is based on in-line measurements and does not provoke congestion to make the estimation of the available bandwidth. The graph shows how this new proposal behaves and approximates the real available bandwidth.

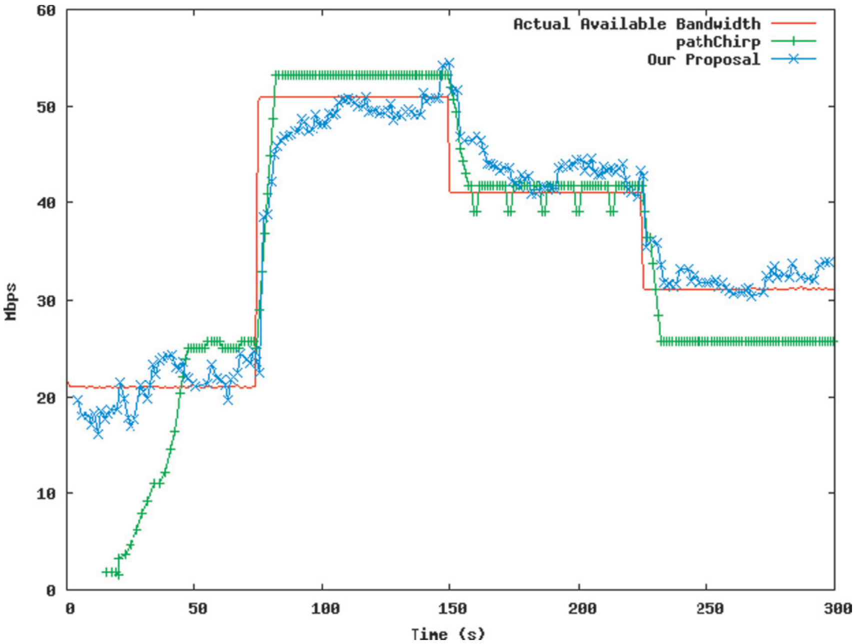

Fig. 15.4 Available bandwidth estimation

As part of the delivery infrastructure the principles of P2P caching are for example being investigated. Initial work in this area has focused on how P2P caches can be structured, dynamically established, and how the different elements are coordinated. The goal of P2P caching is to bring content close to the user. However, in contrast to "normal" caching, caches are not required after a content item has reached a certain popularity since at this stage it will be widely available in the vicinity. The idea is that peers are elected (based on request frequency) to join the P2P cache. Content is cached according to requests and after this content is available, it is taken from the cache. A simulation study has been carried out assuming between 5000 and 7000 nodes and different download scenarios. The study shows that the major overhead is caused by coordination interaction between the caching nodes. This is offset by bandwidth savings due to bringing content closer. It is also found that the bandwidth that can be saved is considerable, whereas the additional effort is marginal. However, the size of the content items and access patterns are crucial. Further work can be carried out to establish how this changes with varying download speeds and content penetration scenarios.

Besides the use of simulation tools, some prototypes are being developed to show the applicability of the research results in a realistic scenario in the field of content delivery in community networks. Several application scenarios are identified, based on existing commercial services, to validate the architectural framework. In particular, we investigate a VoD application scenario that enhances a community Web portal with video and by building a P2P application as add-on to their client-based community portal. Both the community members and the community provider can offer videos for downloading. These videos can be for free or paid content. For example, a golf player's community can offer typical paid content such as professional golf videos (e.g. report of a PGA tournament). It can also offer private videos but paid content (e.g. a video of a golf trainer about how to improve your practice) or totally free content.

15.6 Conclusion

Community networks provide many opportunities for new content services as well as for the communication and interaction of community members. In this model the community members provide the resources in terms of networks and nodes, e.g. in the form of wireless mesh networks, and they provide, manage, and use content. Since these are typical end users that do not necessarily have special training in network management and system administration, autonomic solutions at the network and overlay level are very important to reduce the necessary human intervention in order to establish and maintain content delivery infrastructures. Wireless networks and mobility play an important part in these delivery infrastructures. Therefore, it is important that services can be dynamically adapted to available resources. To provide the foundation for self-adapting solutions, one of the most important research challenges is to understand and model cross layer interactions and dependencies among functions and among metrics. Furthermore, services need to be dynamically composed out of simple service instances to exactly provide the services that is required by the users with respect to their functional needs and the available resources.

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