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IPTV Deployment – Trigger for Advanced Network Services!

The increasing popularity of multimedia broadband applications, beyond basic triple-play, introduces new challenges in content distribution networks. These next-generation services are not only very bandwidth-intensive and sensitive to the high delays and poor loss properties of today's Internet, they also have to support interactivity from the end user. The current trend is therefore to introduce IP-aware network elements in the aggregation networks to meet the increasing QoS requirements, offering a smooth transition from legacy ATM-based platforms towards more scalable, efficient and intelligent access networks. One of the promising services triggering this evolution is IPTV. This article presents a large-scale IPTV service deployment in an IP-aware multi-service access network, supporting broadcast TV, time-shifted TV and pay-per-view services. Transparent proxy caches collaborate providing distributed network storage and user interactivity, while offering an adequate end-to-end quality of experience. As a use case, a time-shifted TV solution is introduced in more detail. We discuss a distributed caching model that makes use of a sliding window concept and calculates the optimal trade-off between bandwidth usage efficiency and storage cost. A prototype implementation of a diskless proxy cache is evaluated through performance measurements.

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different services have highly fluctuating bandwidth requirements

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Introduction

Although telecom operators continue to build out their broadband access networks to improve high-speed Internet access and voice-over-IP (VoIP) services, IPTV services are becoming the highest-priority residential telecom services, creating very promising market opportunities. These bandwidth-intensive IPTV services have a significant impact on the underlying transport network and require more intelligent access network elements to meet the higher QoS requirements.

IPTV is therefore considered as an important driver for other advanced network services.

As a consequence, the architectural model of access networks has evolved towards multi-service and multi-provider networks during the last few years. Ethernet as well as full IP alternatives have been investigated as viable connectionless successors for the legacy ATM-based platforms. While the introduction of Ethernet up to the edge solves some of the existing access network problems, new ones are created. Per subscriber traffic segregation and the lack of QoS support are the main issues of standard Ethernet. While the introduction of VLANs could alleviate these shortcomings, it can be questioned whether this approach is sufficiently scalable for larger access network deployments. Therefore an IP-aware network model[1] is often considered a valuable alternative.

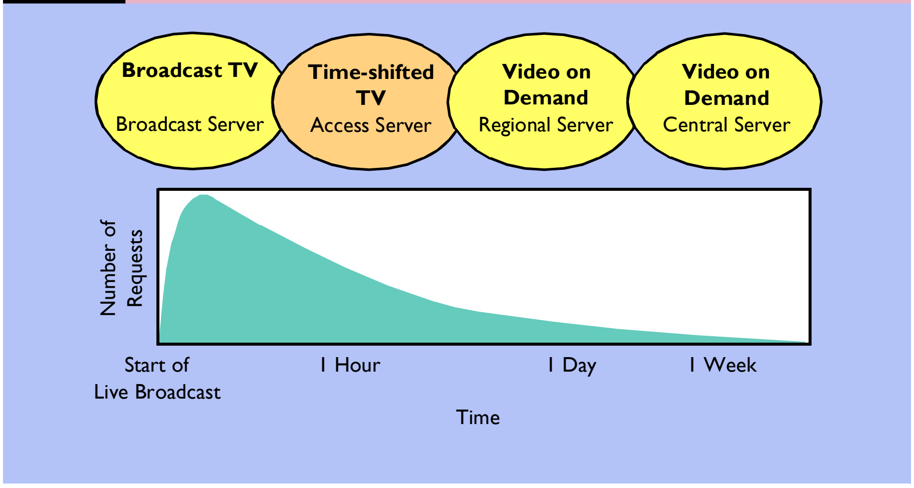
Depending on the popularity of the content, different IPTV services can be distinguished (Figure 1). While traditional live TV is broadcast from a central server deeper in the network, video-on-demand (VoD) servers are typically located at the edge of the core network. In order to support interactivity from the end user for live TV or to serve requests for other very popular content, servers in the access network can become beneficial. This approach, however, has important implications for future access network architectures, as discussed further on in this article.

Next-Generation Broadband Services

Next to IPTV services, a wide variety of other value added (interactive) services, such as managed home networking, home automation and security management, multimedia multi-party conferencing and on-line gaming, can be offered by service providers, each setting its own requirements for the underlying network. Different services have highly fluctuating bandwidth requirements. Delay and jitter requirements also differ from service to service.

For interactive services a low delay over the network is a critical success factor. When several parties exchange information in an interactive way, the quality of the user

Figure 1 Delivery mechanisms for IPTV

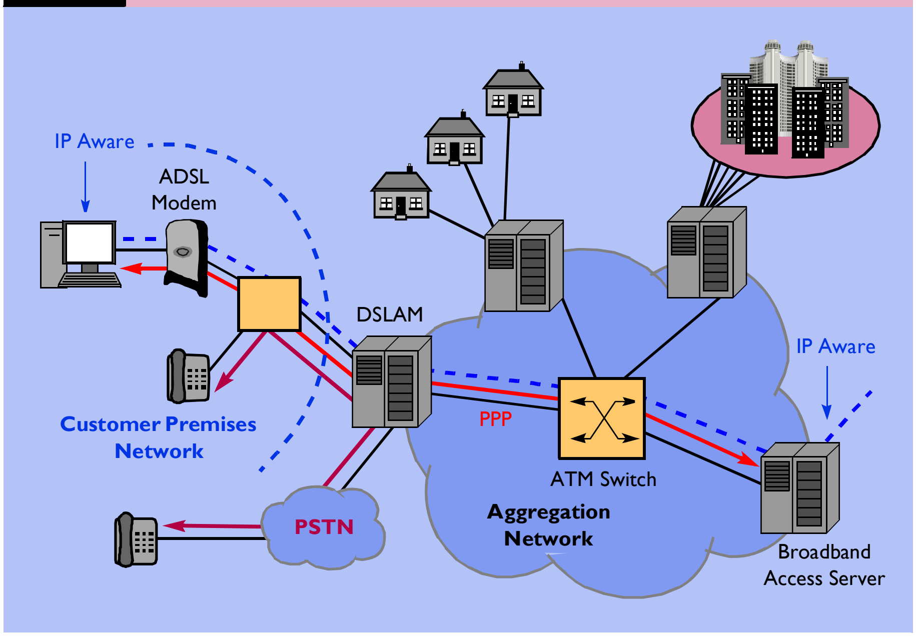


experience (QoE) decreases with increasing delay. For instance, a telephone conversation will become very difficult if the network delay exceeds a few 100 milliseconds. Multimedia services are very sensitive to jitter – variation in the delay will drastically degrade audio and video quality – but, in non-interactive cases (e.g. video-on-demand), some delay can be tolerated.

Some services, such as firewalls and intrusion detection systems for managed home networking, interact directly with the network layer and could be deployed on a large scale inside the access network. Other services mainly focus on the application layer, but even these services could benefit greatly from enabling technologies in the access network, e.g. a caching system in the access multiplexer supporting multimedia content delivery.

However, several shortcomings of operational DSL access networks prevent further generalisation of the Internet and the introduction of such new services.

Figure 2 Current access networks



Current network access implementations

For telephony, a switched path is set up over the PSTN (public switched telephone network) between the end-devices of the caller and the called party. For DSL (digital subscriber line) broadband Internet access, end users set up PPP (point-to-point protocol) connections inside ATM VCs (asynchronous transfer mode/virtual circuits) from their customer premises network (CPN) to a central aggregation node, the broadband access server (BAS). Only the tunnel end-points are IP aware. When an end user wants to connect multiple IP devices to the Internet, a NAT (network address translation) router is used to terminate the PPP connection. Although geographically similar, PSTN and DSL networks are physically separate, except for the first mile. Broadcast TV is distributed over yet another access network (e.g. cable, satellite).

Implications for the Access Network Architecture

Network transformation

The connection-oriented approach of current DSL (digital subscriber line) access networks (see Figure 2) has been identified as a limiting factor, both in terms of access network scalability – all PPP (point-to-point protocol) links are terminated in a single device, the broadband access server (BAS), and obstruct multicast support in the access network – and subscriber terminal autoconfiguration – PPP links cannot be autoconfigured as the link specification is location dependent. Also, since PPP access networks are tailored to the connection of a single device per subscriber, network address translation (NAT) is required on subscriber lines where multiple IP devices are connected, breaking end-to-end IP connectivity.

Furthermore, introducing new services, all imposing their own QoS (quality of service) requirements, is impossible over a single best-effort access link as it exists today.

To overcome all these issues, a converged IP access network architecture, as depicted Figure 3, was introduced by Stevens et al[2], showing how an IPv6 data-plane can be used as the cornerstone of a future service-oriented access network:

- IP awareness close to the end user is required for the deployment of new advanced services in the access network;
- a converged access network reduces the capital and operational expenses (CAPEX and OPEX) of maintaining per service separated networks – furthermore, interaction between different services is more flexible;
- due to its connectionless nature, an IP access network allows for multiple edges, greatly improving scalability and robustness in case of edge node failure;
- in light of the growing peer-to-peer traffic volume, the ability to process local traffic without edge involvement further increases the scalability of an IP access network.

An overview of the most important elements in the network transformation process is given in Table 1[3].

Network processing power

Because each service has its own requirements for the characteristics of the underlying network, advanced QoS support will be a critical success factor for such a converged access network, requiring additional processing power to be present in

Figure 3 **Evolution towards a converged, IP-aware, full service access network**

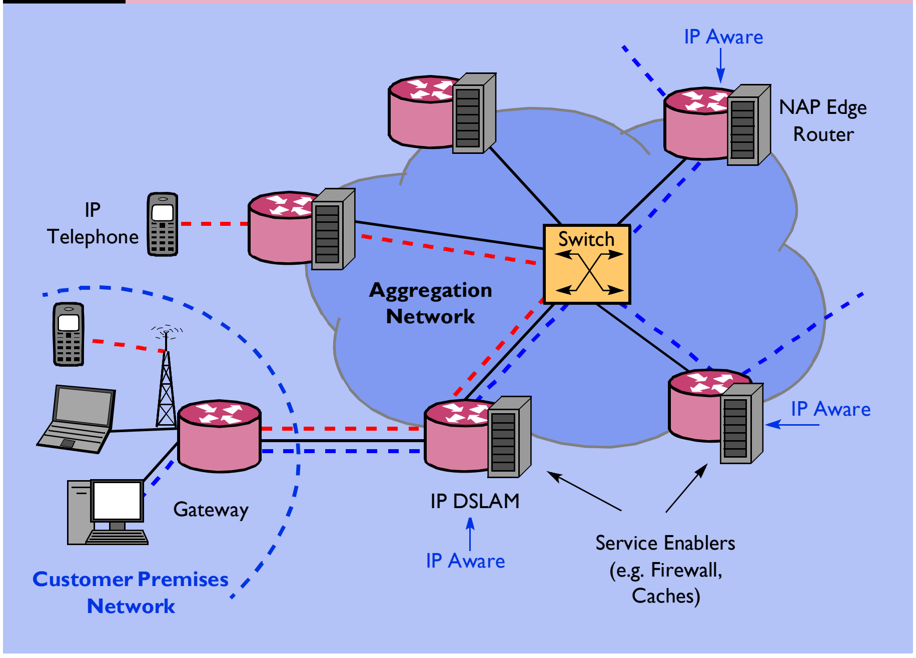
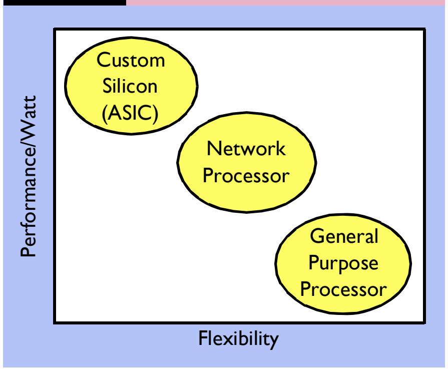


Figure 4 **Taxonomy**



IP access nodes. Furthermore, the deployment of service enablers or even full services in the access network puts additional strain on the access nodes' processing units.

Traditionally, telecom equipment vendors have used fixed-function application-specific integrated circuits (ASICs) to cope with the huge performance requirements of today's network systems. However, the ever-changing requirements of a service oriented access network require flexible solutions with assured time to market, while custom silicon provides little or no flexibility to introduce new protocols or services on existing hardware.

As opposed to ASICs, general-purpose processors certainly meet the flexibility requirements for implementing modern network services.

However, they often lack performance or consume too much power (generate too much heat) for integration in large telecom systems.

For this reason, a hybrid device, called a network processor (NPU), has emerged over the last few years. Network processors are highly parallel, programmable hardware, combining the low cost and flexibility of a RISC processor with the speed and scalability of custom silicon[4] (see Figure 4). NPUs are considered an important technology for increasing application awareness of IP access nodes.

Table 1 **Network Transformation Process for Triple Play**

Current ATM-based broadband aggregation		Next-generation Ethernet/IP-based broadband aggregation
ATM DSLAMs		IP DSLAMS
• unintelligent layer 1 aggregation • low-speed ATM uplinks • mostly central office-based	⇒	• intelligent aggregation with multicast support • gigabit Ethernet uplinks • increasingly RT-based
Complex, fixed connections		Simple, flexible connections
• PPP-based • bound to DSL, CPE in the house • provisioning cost high	⇒	• DHCP-based • independent of device • user-based • provisioning cost low
Centralised B-RAS		Distributed routers
• optimised for best-effort Internet • lack of scalable routing and QoS • typical OC-12 hand-off to IP core	⇒	• optimised for QoS-sensitive services • highly scalable • 10 GbE hand-off to IP/MPLS core
Lack of network resiliency		High available network
• outages tolerated • minimal financial repercussions	⇒	• little to no tolerance of service interruptions • risk of churn if reliability metrics are not met

Source: Yankee Group 'Inside the Trends and Numbers of the Broadband Aggregation Market', June 2005

IPTV Service Deployment

Time-shifted TV

Due to the growing popularity of IPTV, a central server architecture has become insufficient to support these services. Recent deployments therefore introduce distributed servers at the edge of the core network, storing the more popular programmes. The time-shifted TV (tsTV) concept, however, as explained in more detail in the next section, goes even one step further and introduces the storage of small sliding intervals of streaming content in the access network. This way smaller, diskless streamers can be deployed close to the end users, at the proxies. This is most beneficial, in terms of network bandwidth, for very popular content, such as live TV shows on the major channels. Support of interactive commands (pause, fast forward or rewind) on live TV then becomes possible at the proxies, at least within the time window of the stored interval.

Distributed storage

End users have an increasing amount of multimedia data (digital photo albums, digital home videos, a digital music and movie collection, etc). A major opportunity of multiservice access networks is allowing users to transparently store, access and share their digital media library from anywhere. While hard disks are failure prone and recordable optical media only have limited archival lifespan[5], having a high-speed network storage service, enabling users to virtually take their data with them wherever they go and relieving them of the burden of meticulously backing up all data, would make life a lot easier.

Guaranteeing fast access requires distributed servers and a pervasive replication mechanism, as introduced in Saito et al[6], caching data wherever and whenever it is accessed. Since multimedia content is typically read-only data, no strong consistency is required between replicas.

the popularity of a television programme typically reaches its peak within several minutes after the initial broadcast of the programme and exponentially decreases afterwards

Updates can be propagated periodically, at the same time deciding whether a replica should be retained or deleted (e.g. based on last access time, access frequency). A minimum set of replicas should be maintained at all times in order to ensure reliability. A further speed-up of data access and sharing could be achieved by deploying small caches close to the end user, operating in a manner analogous to the tsTV proxies.

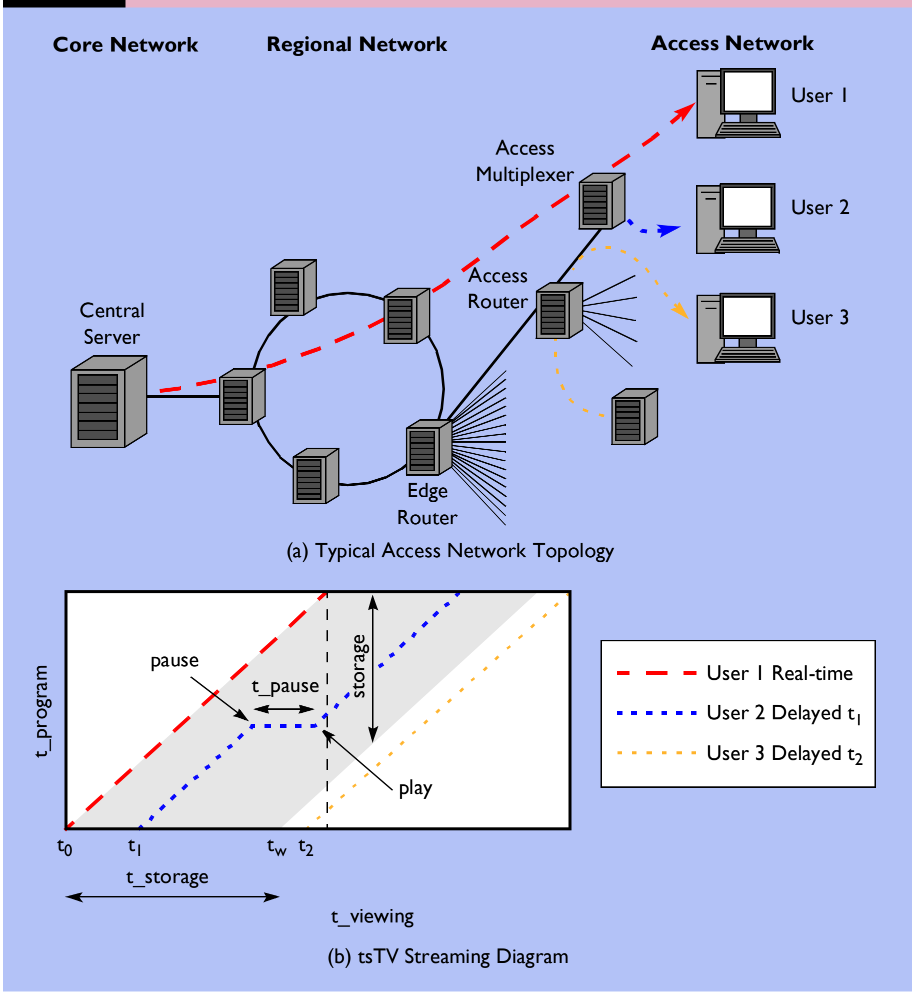
Use Case: Time-shifted Television

Concept

Time-shifted TV enables the end user to watch a broadcast TV programme with a time shift, i.e. the end user can start watching the TV programme from the beginning although the broadcasting of that programme has started or is even already finished.

As shown in Figure 1, the popularity of a television programme typically reaches its peak within several minutes after the initial broadcast of the programme and exponentially decreases afterwards. This means that caching a segment with a sliding window of several minutes for each current programme can serve a considerable part of all user requests for that programme, from start to finish, hence the benefit of using distributed streamers with limited storage capacity. In Figure 5(a) and Figure 5(b) for example, user 1 is the first to request a certain television programme and gets served from the central server. Afterwards, other requesting users (e.g. user 2) can be served by the proxy, as long as the window of the requested programme is still growing. After several minutes, the window stops growing and begins sliding, so that user 3 cannot be served anymore and will be redirected to the (central or regional) server or, in case of co-operative caching, to a neighbour proxy with the appropriate segment, if present. Pausing (parallel to the horizontal axis, Figure 5(b)) can also be supported within the segment window, as well as fast forward or rewind (parallel to the vertical axis).

Figure 5 Time-shifted television



(a) Typical Access Network Topology

(b) tsTV Streaming Diagram

Caching algorithm

Our caching algorithm for tsTV services is presented in this section. Since we assume that in general only segments of programmes will be stored, cache sizes can be limited to a few gigabytes in stand-alone mode or even less in case of co-operative caching. This way smaller streaming servers can be deployed closer to the users, without increasing the installation cost excessively.

We virtually split the cache into two parts – a small part S and a main part L. Part S will be used to cache the first few (e.g. 5) minutes of every newly requested (or broadcast) programme, mainly to learn about its initial popularity. Its size is generally smaller than 1 GB (typically 1 hour of streaming content).

Part L will be used to actually store the appropriate segments (with growing or sliding windows). These segments and their window size are chosen based on local popularity (especially useful in cases of stand-alone caching), distance from the end user (important in cases of co-operative caching) or a combination of both metrics. Figure 6 shows the basic principle of the tsTV caching algorithm.

We assume that all caches know which segments are stored on the other caches, through a cache state exchange (CSE) protocol.

Deployment options

To demonstrate both deployment options, stand-alone or co-operative caching, simulations were performed on the typical access network topology shown in Figure 5(a). The server offers five popular channels through the tsTV service, each with six programmes of 45 minutes per evening.

The popularity of each programme reaches a peak during the first interval (= 5 min) after the start, and is halved after each subsequent interval (similar to Figure 1), so that all requests for each programme are made before the programme has ended.

Figure 7 shows the load on the different links between the edge server (ER), the access routers (ARs) and the access multiplexers (AMs) from Figure 5(a). In stand-alone mode, requests that cannot be served by the cache at an AM are forwarded to its AR cache and, if necessary, forwarded to the ER (hierarchical). In co-operative mode, caches are present at the AMs only (no hierarchical caching), forwarding requests among each other effectively, using real-time streaming protocol (RTSP) messages[7].

In co-operative mode, the server load decreases n times faster than in stand-alone mode without hierarchical caching, where n is the number of AM caches (6 in Figure 7). At low cache sizes (< 1 GB), the access network traffic due to the cache co-operation is relatively high. When using larger caches, this load is reduced as well, since most requests can be served locally.

Figure 6 Basic principle of the tsTV caching algorithm at each proxy

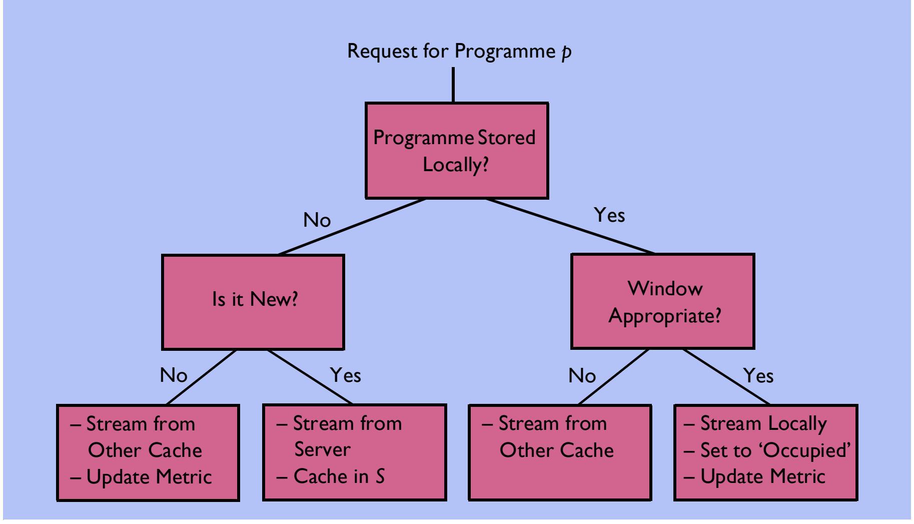


Figure 7 Relative load on the links between ER, AR and AM (upstream and downstream) for hierarchical and co-operative caching

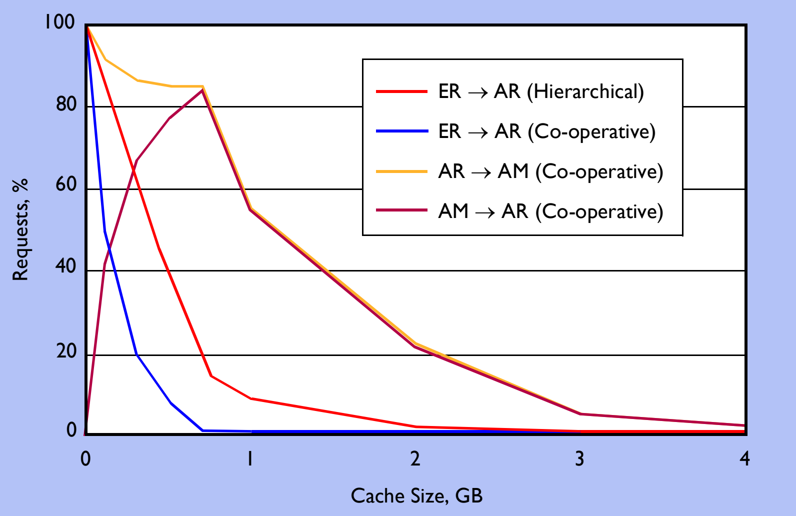
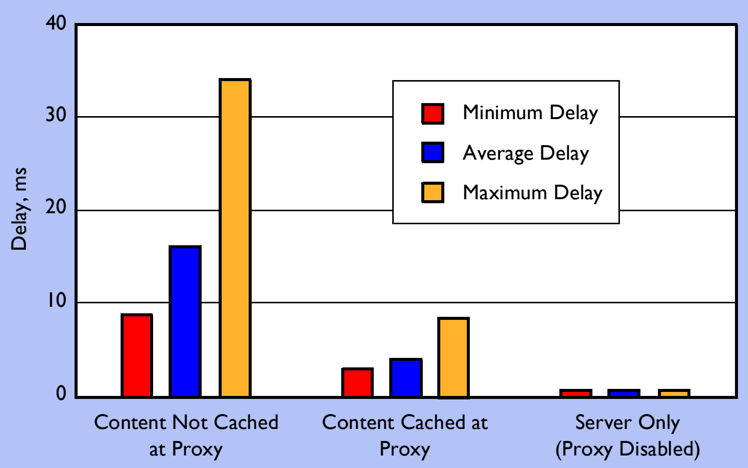


Figure 8 Delay between a client request and the actual start of the RTP stream on a client PC



RTSP proxy

A transparent RTSP proxy for time-shifted TV has been implemented for evaluation purposes. An overview of the performance measurements on an AMD Athlon™ 64 processor 3000+ (512 MB RAM) is presented in Wauters et al[7]. Figure 8 shows the delay between a PLAY request sent by a PC client and the arrival of the first RTP packet at the PC client, for different configurations (server-proxy-client). Even when the proxy has to fetch the content from the server, the delay is never higher than 35 ms (1000 measurements per configuration). When the proxy acts as a mere router, the delay caused by the server is less than 1 ms. The delay on the network links between server, proxy and client is negligible.

Conclusions

In this article, the necessary transformations in access network architectures for next-generation broadband services have been described. Improved scalability, flexibility and availability can be achieved through the introduction of IP-aware network elements.

when the proxy acts as a mere router, the delay caused by the server is less than 1 ms – the delay on the network links between server, proxy and client is negligible

Due to their significant bandwidth requirements and steadily rising popularity, IPTV services have been identified as the main trigger for this evolution, offering opportunities for service providers to introduce other value added (interactive) services. One of the most promising IPTV services is time-shifted TV, which can be deployed using diskless distributed caches, effectively offloading the server and transport network.

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