

In-home Video Distribution for Telecom Operators

We have investigated the various alternatives for in-home video distribution that might be applicable between now and 2010. Among these are wireless and so-called *no-new-wires* architectures, but also unconventional approaches based on analogue distribution. The latter actually led to a surprisingly attractive and realistic solution. Thereupon we have developed an innovative demonstrator, which is basically a centralised video gateway equipped with analogue modulators that can be connected to the existing in-home coaxial cabling.

Introduction

With the advent of truly broadband access networks, convergence of voice, data and audio/video services is now within reach of telecom operators. But before a mass market can be achieved, many issues should still be solved. A considerable challenge is the user-friendly distribution of video data from the broadband modem to the various television sets in the home. This issue arises from the fact that televisions are usually not placed close to the operator's demarcation point. For digital video offered by telecom operators, current solutions mostly involve wiring the home with unshielded twisted pair (UTP) cables from the modem to dedicated set-top boxes for every television. Having to re-cable the home and to purchase set-top boxes significantly impedes potential customers to abandon their current service provider and subscribe to television services offered by a telecom operator. We have therefore investigated various alternatives for in-home video distribution that might be applicable between now and 2010.

This paper first describes current developments in the offering of triple-play services, and shows that the use of operator-friendly as well as user-friendly home networks is unavoidable for creating a profitable proposition. We then analyse several current and future digital home network technologies in terms of properties that are necessary for flawless video distribution: bandwidth, range, quality-of-service (QoS) support and security. For the home network standards that turn out to be suitable, we then compare two different architectures: a decentralised architecture

based on Internet protocol (IP) distribution to various set-top boxes, and a centralised architecture based on a single video gateway and analogue video distribution directly to the television sets. The latter led to a quite attractive and realistic solution. We therefore conclude the paper with a description of our video gateway demonstrator.

Recent Developments with Respect to Triple-Play Services

The expression *triple-play services* is open to many interpretations. A consumer might experience triple play when he/she has integrated services digital network (ISDN) telephony, asymmetric digital subscriber line (ADSL) Internet access and satellite TV from a single provider, and receives a monthly invoice covering all subscription fees. However, triple-play offerings in the near future are expected to include also video-on-demand services, personal video recording, electronic programme guides, video telephony, etc.

Recently, the deployment of triple-play services over IP networks has gained much attention, especially in parts of Asia, Europe and North America where the penetration of broadband Internet over cable and ADSL access has reached critical mass. Therefore, this paper narrows the scope of triple-play services as a combination of Internet, voice and video services over a single terrestrial broadband access network based on IP (see Figure 1). For the coming five years, the IP broadband access network can be based on cable, ADSL2+, very-high-rate digital subscriber line (VDSL) or fibre access networks, typically owned by telecom operators and cable operators. In The Netherlands, about 40% of the households are now connected to such a broadband access network. With that, The Netherlands has one of the highest broadband penetration rates in Europe.

The ruinous competition between cable and telecom operators now extends to the home network. With respect to video services, both cable and DSL operators use set-top boxes (STBs) to display digital TV on normal television sets, since the majority of the consumer market does not have television sets with built-in digital tuners or IPTV

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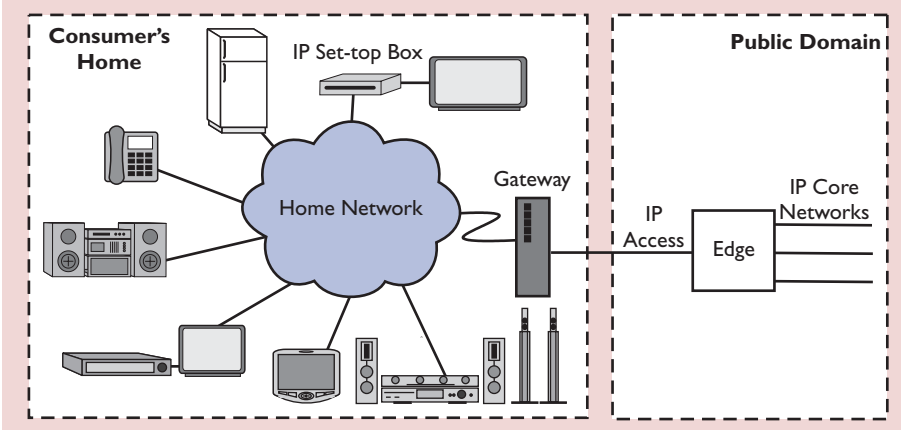
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Figure 1 Schematic architecture for the delivery of triple-play services over an IP network



tuners yet. The primary function of digital STBs is to enable an analogue television to receive digital video signals. A typical STB contains one or more microprocessors for running the operating system and for processing and decoding the Moving Pictures Expert Group (MPEG) transport stream. The STB can be connected with the TV using a Scart connector or a coaxial connector. For each television set, a separate decoder is required, assuming that every television should be able to show images independently. This seems to give the cable operators a head start on the telecom operators in the run for digital TV market share, because they can maintain analogue broadcast to every TV set in the home that is not yet provided with a digital STB. Only in the long term is it expected that TVs might have an integrated decoder. At the moment, integrating a decoder would lead to an unacceptable reduction of the TV's depreciation time, because codecs are still rapidly evolving and are not properly standardised.

There are two different types of digital STBs: IP STBs and digital video broadcast (DVB) STBs. DSL network operators deliver a limited number of parallel video-over-IP channels to IP STBs in the home. The actual switching of the channels when the consumer 'zaps' takes place somewhere in the operator network. Current DVB network operators (cable, satellite, terrestrial, etc.) deliver up to several hundreds of digital channels to the home, and switching between channels takes place in the DVB STB itself. Because DVB does not offer the bidirectional IP infrastructure that is needed for video-on-demand type of services and interactivity, also DVB operators will migrate to IP video in the long term. In this paper, only IP STBs are considered.

Basically, there are no major technological bottlenecks anymore that prevent the introduction of triple-play services over IP. This includes all necessary home networking technology. The key question is how to make the proposition profitable for all parties involved in the triple-play value chain. In our vision, (at least) two funda-

mental requirements must be met for such a triple-play proposition. First of all, triple play must be comprehensible for the consumer. It must be easy to install, maintain and operate. Complexity scares people, and can lead to very unhappy customers if not taken care of properly. The whole concept of home networking, connected devices and its possibilities is quite revolutionary to the average consumer and requires a new mindset. Secondly, triple-play service providers must be able to manage at least some of the characteristics of connected devices such as residential gateways, STBs and, ultimately, consumer electronics to guarantee QoS and security to the end-user. Said otherwise, the soft factor 'no hassle for the end-user' is determining the success of triple-play services more than the hard factor 'enabling home networking technology'. The remainder of this paper therefore focuses on finding home network architectures that are user friendly as well as operator friendly. Of particular interest is the support of video services, since video service delivery causes most of the challenges to the home network.

Home Networking Technologies

In The Netherlands, about 50% of the households with broadband access have their digital devices mutually connected by means

of a home network. For the distribution of IP traffic within the home, there are many different standards available. An overview can be found in Reference 1. Ethernet has been the prevailing standard up to the end of the nineties, but because of its inconvenience with respect to installation, many wireless alternatives have been developed in the past decade. The most important wireless technologies currently available are the Institute of Electrical and Electronics Engineers (IEEE) standards 802.11b and g, and the newest version (1.2) of Bluetooth. The IEEE 802.11a standard is not allowed in Europe. An alternative technology that is allowed in Europe is the European Telecommunications Standards Institute (ETSI) standard digital enhanced cordless telecommunications (DECT). Furthermore, a couple of promising so-called no-new-wires industry standards have been developed recently, namely HomePNA (Home Phone line Networking Association) and HomePlug. They use the already installed telephony network and power-line network respectively, without disturbing the legacy telephony and power services. At the moment, about 50% of the home networks in The Netherlands are based on UTP Category (Cat.) 5 cables. About 35% use IEEE 802.11b. The rest uses Bluetooth, HomePNA, DECT, etc.

Table 1 summarises the main properties of these technologies. The bandwidth is specified for the physical layer (the raw data rate) as well as for the application layer based on transport control protocol over IP (TCP/IP) traffic. The latter number is measured in our laboratories or taken from the literature (for example, Reference 1). The coverage is not given as a quantitative distance, because it would not have significant meaning for indoor environments. Instead, we indicate if the technology typically covers the whole house, a couple of rooms, or just a single room. In Europe, HomePNA covers only a couple of rooms, because a typical household has only 1–2 telephone jacks. A standard scores 'yes' on QoS support, if it includes any QoS mechanism, such as prioritisation of service classes.

Table 1 Digital home networking technologies that are mature in 2005

Technology	Bandwidth Mbit/s (L1/L7)	Typical Coverage	QoS Support	Security
Ethernet	100/70	whole house	yes	+
IEEE 802.11b	11/5	2 rooms	no	–
IEEE 802.11g	54/25	2 rooms	no	–
DECT	2/~2	whole house	yes	+
Bluetooth 1.2	0.7/0.4	1 room	yes	0
HomePNA 2.0	10/6	2 rooms	yes	+
HomePlug 1.0	14/5	whole house	no	0

In Ethernet this can be realized with virtual local area network (VLAN) switching. A technology scores a plus (+) on security, if it supports any user-friendly (!) way of securing the network. Ethernet is inherently secure because it is wired. The security mechanisms of the 802.11 standards are fairly advanced, but not user-friendly. HomePlug is a wired standard, but the wires are so badly shielded, that the signals are also radiated into the air. The main conclusion that can be drawn from Table 1 is that there is only one secure technology with sufficient bandwidth, QoS support and security measures for video distribution within the home. It is Ethernet.

Several new technologies are expected to play an important role in home networking in the future. They are listed in Table 2. IEEE 802.11n is using the recently developed multiple input multiple output (MIMO) technology. Ultra-wideband (UWB) is basically a standard for wireless personal area networks (WPANs) and is partly standardised as IEEE 802.15.3a. HomePlug Audio Video (AV) is the successor of HomePlug 1.0. HomePNA 3.0 can use the existing in-home coaxial network in addition to the in-home two-wire telephone network. From Table 2 it can be concluded that HomePlug AV, HomePNA3.0 and IEEE 802.11n all present good future candidates for user-friendly digital video distribution within the home.

Analysis of Current and Future Architectures for In-home Video Distribution

One of the issues that still have to be settled is how decoding functions should be distributed in the home network. Should the decoding happen centrally, resulting in analogue in-home distribution of the TV signals, or should every TV have its own decoder? Although most of the current home networking research and development focuses on digital networks, it is not clear if they should also be used for streaming video. Excellent papers have been written on this matter (for example, References 2–4), but no definite conclusions could be made. We have re-assessed this question by taking into account many more criteria and trying to analyse them in a quantitative fashion. We also considered the influence of timing: in the short term (2005–2006), the ideal home network architecture might be different from the long term (~2010). In the remainder of this paper, the decentralised architecture is also called the *STB configuration*. The other, centralised solution is called the *video gateway configuration*.

A video gateway is basically a single device that does the decoding for all the

Table 2 Digital home networking technologies that are expected to be mature in ~2010

Technology	Bandwidth Mbit/s (L1/L7)	Typical Coverage	QoS Support	Security
Gb Ethernet	1000/700	whole house	yes	+
IEEE 802.11n	100/50	2 rooms	yes	?
UWB	200/?	1 room	no	+
Bluetooth 2	3/?	1 room	yes	+
HomePlug AV	140/70	whole house	yes	0
HomePNA 3.0	128/60	whole house	yes	+

televisions in the home. In this case, two issues have to be solved. First, the decoded (analogue) signal has to be transported to every television set and, secondly, it must be possible to control this video gateway remotely to switch channels and content. Video transport methods such as Scart and high-definition multimedia interface (HDMI) are limited in their maximum range. For the distribution of the decoded video signals, this proves them useless for serving all television sets in the home from one central location. A better solution is found by reusing the in-home coaxial wiring, and broadcasting the video signals from the video gateway to every television via radio-frequency (RF) phase alternating line (PAL) transmission. The gateway then transmits one ‘channel’ per television in the home, and each television set is permanently tuned to its own fixed frequency. The video gateway can be controlled remotely by small infrared (IR) receivers located at every television that pick up the IR signal and send it to the video gateway via the coaxial cable.

A typical STB configuration for 2005 is shown in Figure 2, and a typical video

gateway solution in Figure 3. The two configurations are assessed on 20 requirements. These requirements follow from many years of user experience research (for example, Reference 5) and market research (for example, References 6 and 7). The requirements are:

- Functional requirements:
- A PC should not be required in the home network.
 - The home network should have enough bandwidth.
 - It should be possible to watch television at any place in the house.
 - Besides broadcast channels, also personal content (DVD, PVR, etc.) should be available at each TV.
 - The solution should support 4:3 and 16:9 aspect ratios.
 - The solution should support high-definition television (HDTV) quality.
 - The solution should support Dolby surround sound.
 - Channel switching (‘zapping’) should be fast enough.
 - The architecture should be modular (easy to extend and personalise).

Figure 2 A typical set-top-box configuration (‘decentralised’), using current home networking technologies

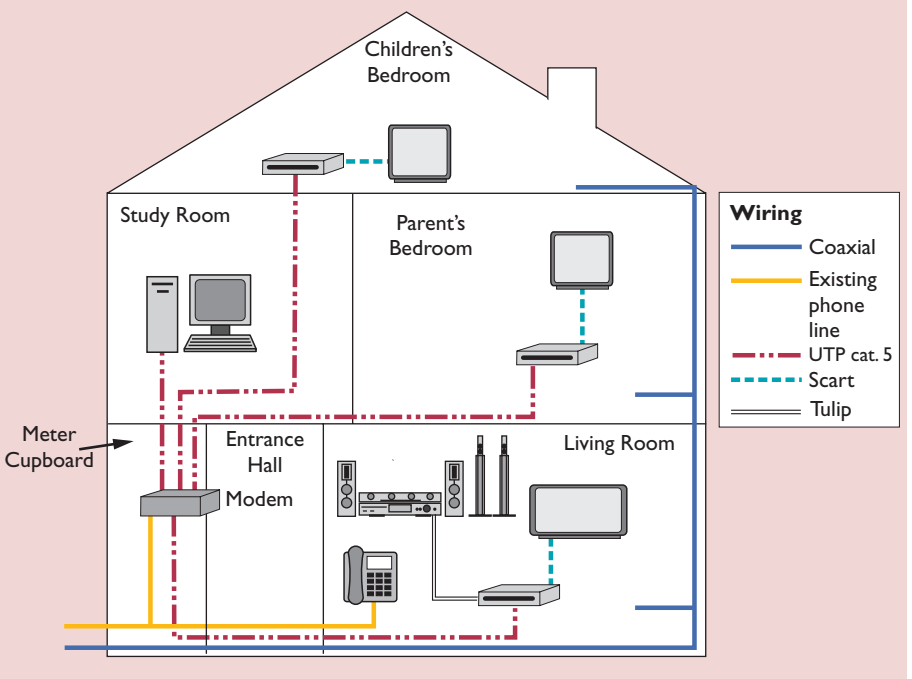
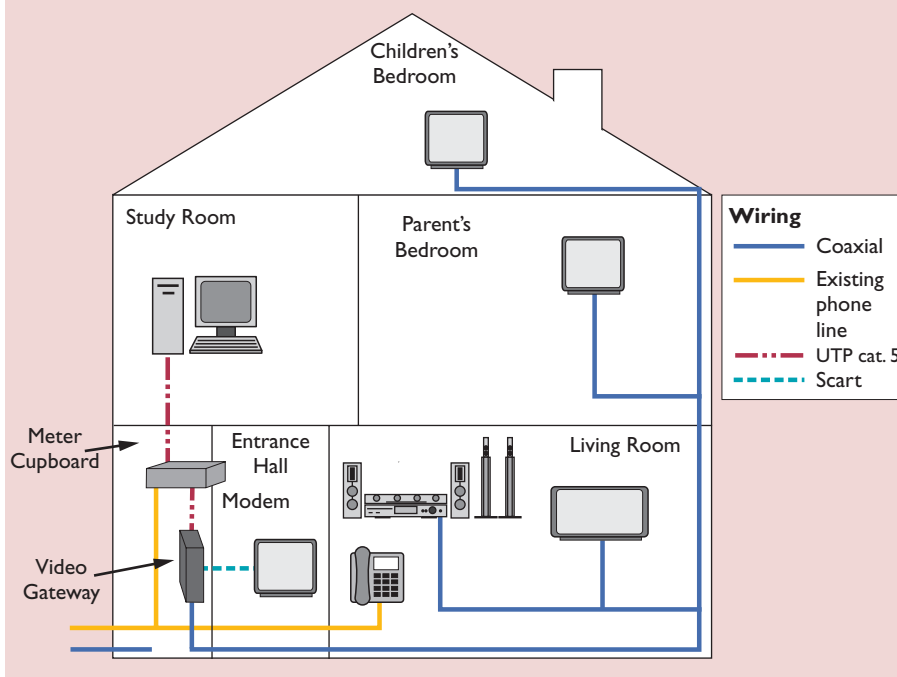


Figure 3 A typical video gateway configuration ('centralised'), using current home networking technologies



- A minimum of three televisions and radios can be used simultaneously.
 - The solution should have an acceptable user interface.
 - The system can be remotely managed.
- Other requirements (market, usability, operational, regulatory, etc.):*

- Service personnel, the helpdesk, and the users need a minimum of training.
- The solution is legal.
- The technologies that are used are standard.
- The solution should have little impact on operational processes of the operator.
- The solution should consist of only a few boxes.

- Installation should take a minimum of time by service personnel and/or users.
- The costs for the user should be less than 100 euros per television.
- The solution should be future-proof.

The configurations can score 0, 1 or 2 on each requirement. On the base of what is known from the literature, each requirement has been assigned a weight from 1 to 3. The requirements which score differently for the two configurations are given in Table 3. Both the STB configuration and the video gateway configuration need IP transport between the broadband modem and the STBs or video gateway, respectively. For the short term, only configurations that use

Ethernet should be considered. For the long term, also varieties using HomePNA3.0, HomePlug AV, and IEEE 802.11n are addressed.

The scores are rationalised as follows. The PAL standard, which is used with coaxial RF transport, does not support HDTV. Therefore the video gateway solution does not qualify for HDTV services. Since HDTV is going to be deployed by operators after 2005 anyway, only the long-term STB solutions get points here. STBs can support Dolby surround sound. A video gateway can only support it for a single television. The video gateway is a typical short-term solution, compared to IP STBs. Among the various home networking technologies, HomePNA and HomePlug are future-proof only to a limited extent, because they are just industry standards rather than open standards. A distributed IP-based architecture is easier to upgrade because of its modular architecture. An important advantage of the video gateway configuration is that a single personal video recorder (PVR) and digital video disk (DVD) player can serve every television in the house. Theoretically speaking, this is also possible when the PVR or DVD player is integrated in one of the STBs. However, among other reasons, this is not practical, as the best-effort Ethernet network would have to carry multiple channels simultaneously. It is obvious that the centralised solution involves far fewer boxes than the distributed architecture. A distributed architecture based on Ethernet is also relatively difficult to install, compared to the video gateway solution and the architectures based on the future wireless and power-line networks. HomePNA falls somewhere in between,

Table 3 Assessment of the STB and video gateway configurations, considering four different ways of IP transport between the modem and the STBs or the video gateway, respectively

Requirement	Weight	Set-Top Box Configuration				Video Gateway Configuration			
		2005	2010			2005	2010		
		Ethernet	Home-PNA 3.0	Home-Plug AV	IEEE 802.11n	Ethernet	Home-PNA 3.0	Home-Plug AV	IEEE 802.11n
HDTV quality possible	3	0	6	6	6	0	0	0	0
Dolby surround sound support	2	4	4	4	4	2	2	2	2
Future-proofness	1	2	1	1	2	0	0	0	0
Modular solution	1	2	2	2	2	1	1	1	1
PVR/DVD at every TV	3	3	3	3	3	6	6	6	6
Few boxes	3	3	3	3	3	6	6	6	6
Easy to install	3	0	3	6	6	6	6	6	6
Bandwidth	3	6	6	6	6	3	3	3	3
Range of network	3	6	6	6	3	6	6	6	6
Total:		26	34	37	35	30	30	30	30

Note: Only the requirements are given for which the various solutions score differently

because basically no new wires need to be installed, but there are relatively few connection points for the devices, which might lead to some extra wiring anyway. Because the distance between the video gateway and the modem is probably relatively small, there is no preference for any IP network technology here. In terms of range, the IEEE802.11 standards are known to have a limited range in a significant number of houses.

When all the scores are added, the STB solutions with HomePlug AV or IEEE 802.11n come out best. However, these technologies are not available in 2005. For the short-term solutions, the video gateway scores slightly higher than the STB solution. But the difference is small, and therefore confirms the qualitative analyses of References 2-4. In the long term, a home network architecture as depicted in Figure 4, based on HomePlug AV, can be viable.

Example of a Video Gateway Architecture

The centralised solution for in-home video distribution has been further elaborated by the implementation of a video gateway demonstrator. The demonstrator consists of a streaming video server, a video gateway, and two television sets. The streaming video server is connected to the video gateway through a multicast network. It encodes and streams two television channels, contains video-on-demand content, and provides an HTML-based user interface. The video gateway is controlled remotely by small IR-RF converter boxes located at the TVs. They receive the IR signals from the television's remote control and send them to the gateway via the coaxial cable.

The architecture of the video gateway is depicted in Figure 5. The gateway is derived from a PC with a dual-head video card and two sound cards. It runs on a Linux operating system and uses VideoLAN to view and decode the video content. The video and audio outputs are both connected to RF PAL modulators that have coaxial outputs. One output of the video card is also provided to the end-user directly by means of a Scart connector. Also two DVB-T(terrestrial) tuners and a DVD player are implemented in the gateway. As a result, the video gateway supports six independent video input channels (the video-on-demand server, two broadcast channels, two DVB-T channels and the local DVD player) and two independent video output channels that can be connected to up to three television sets (two by means of the in-home coaxial network and one by using the Scart output). The gateway contains a hard disc, so the addition of PVR

Figure 4 Example of a future home network based on HomePlug AV

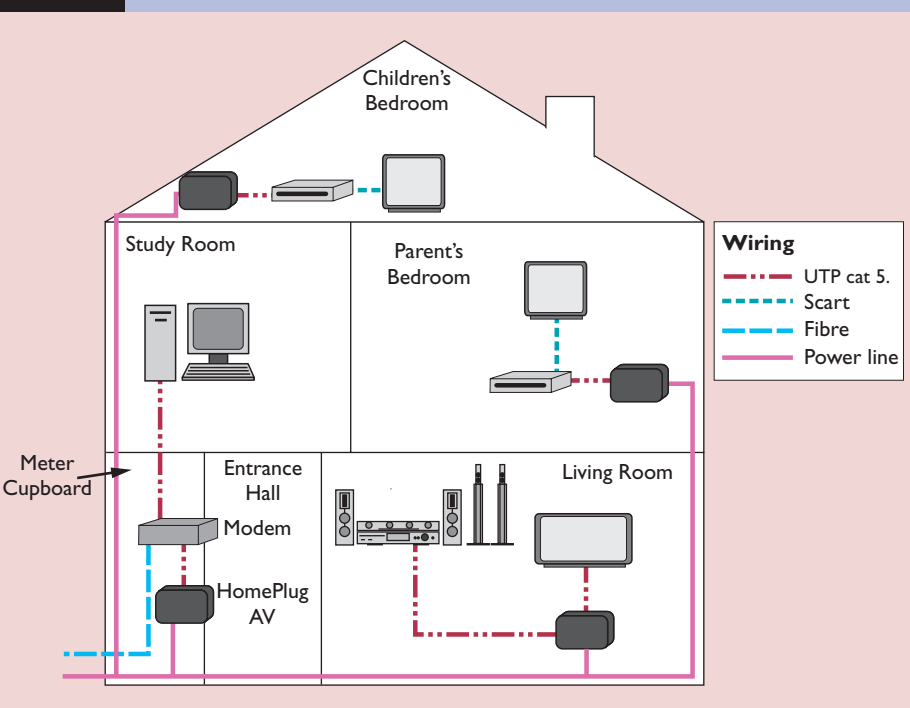
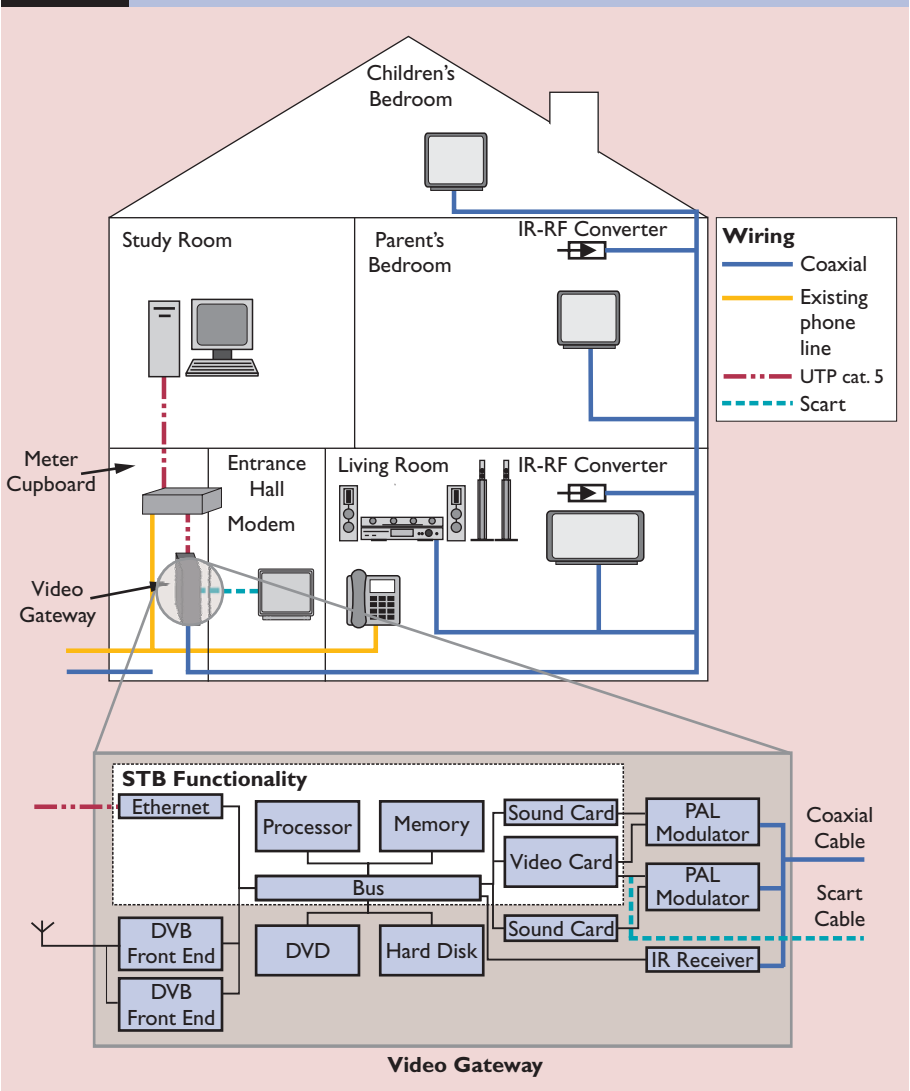


Figure 5 Example of a video gateway architecture



software could easily create a seventh video input. An STB basically contains all the functionality within the white unshaded box ('STB Functionality'). Therefore, it can be readily seen that the centralised architecture is significantly more cost-effective than a decentralised solution with an advanced broadband router modem, a to-be-installed home network, and two or three separate STBs that are able to run software for decoding, DRM, and control.

Experiments with this demonstration set-up show that acceptable user experience is achieved and, therefore, prove that the use of a video gateway can indeed provide a solution for cost-effective and user-friendly in-home video distribution in the short term. The first commercially available video gateways have been introduced to the market very recently⁸.

Conclusions

In the short term, there are no in-home IP distribution solutions available that are suitable for video services, except UTP wiring. A good alternative for households with multiple television sets is the use of a central video gateway that broadcasts one analogue channel per television via the coaxial cable. This solution is attractive to the user because it is easy to install and it does not require new wires. Furthermore, services that run on the gateway, such as a DVD player or a PVR, are available on every television in the home. Finally, the costs of such a centralised solution are probably lower than the aggregated costs of several separate intelligent STBs, a broadband router modem and additional in-home cabling. Therefore telecom operators should consider using a video gateway when they start offering video services.

For 2010 it is expected that technologies such as HomePlug AV and IEEE 802.11n are mature and commercially available. These technologies can then be used for digital in-home video distribution, providing better QoS than analogue transport.

The video gateway can be an important component enabling a first step towards full convergence of telecom and entertainment services. It combines present strengths of both telecom and cable company worlds and can be easily migrated to high-quality, all-digital home networking solutions.

Acknowledgements

The work presented in this paper is partly carried out in the B@Home project, supported by the Freeband Communication technology program of the Dutch Ministry of Economic Affairs.

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