REQUIREMENTS OF TRIPLE PLAY SERVICES TOWARDS BROADBAND ACCESS NETWORKS

B@Home WP0, Deliverable D0.5.2

Colophon

Date :	1-3-2005
Version :	1.0
Change :	Processed Internal and external review comments
Project reference:	B@Home WP0/D0.5.2
Freeband reference :	Freeband/B@Home/D0.5.2
Company reference :	TNO Telecom Rapport 33504
URL :	http://www.freeband.nl/project.cfm?id=498
Access permissions :	Public
Status :	Final
Editor :	R.N. van Wolfswinkel
Company :	TNO-Telecom
Author(s) :	R.N. van Wolfswinkel
Reviewers:	S.S. Op de Beek, J.M.M. de Nijs

Synopsis:

Keywords: broadband, access infrastructures, triple play, service requirements, network capacity, quality of service, security and availability

Abstract

In the current broadband market there are many new developments regarding both services and the broadband infrastructures carrying those services. This paper will address what the requirements of services are towards broadband networks. The focus will be on the requirements of *triple play related services* (telephony, broadcast TV/on demand video and Internet related services) towards the broadband telephony-, cable-, wireless- and fibre-networks.

Table of Contents

Preface

The B@HOME project is part of the Freeband Communication programme, which aims at the generation of public knowledge in advanced telecommunication (technology and applications). Freeband is based on the vision of 4G networks and services. It specifically aims at establishing, maintaining and reinforcing the Dutch knowledge position at the international forefront of scientific and technological developments, addressing the most urgent needs for research and novel applications in the present unfolding of new technology. Freeband comprises more than 25 organisations, including all-important technology providers and many representative end-user organisations. The Dutch Ministry of Economic Affairs is co-funding this programme as part of the BSIK plan

The vision for Freeband for 2010 is to consider communication and information transfer from the perspective of the user, not the provider. The communication infrastructure will become transparent and abundant in all its layers.

B@Home's scope is future broadband services for the residential user, with a focus on the entertainment domain. The objectives of the project are to develop new business models as well as architectures capable of plug-and-play service delivery to the end-user.

The knowledge and experience gained in the project will be used to implement a demonstrator to show some of the future advanced services. In B@Home, Lucent Technologies, Philips Research, LogicaCMG, the Technical University of Eindhoven, Erasmus University of Rotterdam and TNO work together to achieve these results. The project started on July 1st, 2004 and has a duration of four years. After two years, the first demonstrator will be presented.

This white paper is the second result of activity T0.3 "Integrated Broadband @ Home overview", producing white paper documents describing the main results and open activities of the project B@Home and related projects.

1 Introduction

In the current broadband market there are many new developments regarding both services and the broadband infrastructures carrying those services. This paper will address what the requirements of services are towards broadband networks. The focus will be on the requirements of *triple play related services* (telephony, radio/broadcast TV/on demand video and Internet related services) towards the broadband telephony-, cable-, wireless- and fibre-networks.

The requirements of services evolve over time in different ways: existing services change in the way that their (sound, picture, speed) *quality* is enhanced, but also the way services are *used* changes over time. The usage of services is influenced by the number of end-user devices that support broadband services (from PC-only to TV, laptop, personal digital assistant, cordless phones etc.) together with the number of in-home users *concurrently* (at the same time) consuming these services (from a individual user to a complete family). Also sometimes completely new services are invented and might gain popularity.

Assuming change in the *quality* and the *usage* of triple play services as the main driver behind bandwidth and other network requirements chapter 2 of this paper investigates how these services in the past years have evolved and predicts how this will be in the near future.

The current broadband networks are undergoing rapid upgrading mainly focussed on providing more bandwidth to the end-user. These developments together with the increased support for other network requirements like quality of service will be described in chapter 3 in order to see how these network developments are able to deliver what services require. Given the way in which both service requirements and network characteristics change over time, chapter 4 compares these developments to see how the different types of broadband networks (telephony, cable, wireless and fibre) are able to support the growing network requirements of triple play services.

2 The network requirements of triple play services investigated

2.1 What requirements do services have towards the broadband networks?

There are many different services that are currently available in home, and even more when looking towards to the near future. These services can be audio/video entertainment, games, news, education, personal communications, telemedicine, home control, financial Management, asset management and teleworking. These numerous (end-user) services each have their specific requirements. In “Overview of services and applications” (B@Home deliverable 3.1) [2] the requirements of these services regarding (network) traffic and security have been investigated. Using these identified requirements, in this paper we focus at the requirements of *those services using a (IP-based) broadband network that are part of* the so called *‘triple play services’* of telephony (personal communications), radio/TV/on demand video and Internet service) allowing online games, teleworking and file sharing services to be offered).

These triple play services are investigated regarding their requirements that are *network* related.

Bandwidth Requirements:
The most apparent requirement is the speed by which a service needs to be transported over the network, however there are more traffic/speed related requirements, these are explained here:

Data rate and traffic direction: Symmetric/Asymmetric
The most important bandwidth requirement of services is the data rate, this may differ in the up- or downstream direction from narrowband (<128 kbit/s) to mid-broadband (128 kbit/s – 10 Mbit/s) and super-broadband (10 Mbit/s-1 Gbit/s) or even ultra-broadband (>1 Gbit/s). If a service uses more/less in either the up- or downstream direction this connection is called asymmetric (e.g. watching a video uses more downstream capacity), other services use approximately the same speed in both up- as downstream (like placing a telephone call over IP or video-conferencing).
Traffic Duplication: Point-Point, Point-Multipoint, Multipoint-Multipoint
*S*ervices can communicate their information purely to one user (Point-Point) like on demand video (specifically requested by one person), but other services communicate the information to multiple users (Point-Multipoint) like Broadcast Television over IP, or gaming (Multipoint -Multipoint (MM)).
Traffic Pattern: Constant, Variable or Burst
Services sometimes require a constant bit rate connection (like a 128 kbit/s mp3 audio stream) or they can generate traffic varying between a certain minimum and maximum bit rate (like certain variable bitrate streaming video content), or they generate ‘bursty’ traffic at usually a high data rate (like a query on a web page) or a file download.

Network Quality of Service Requirements:

When sharing network resources with other services, most services also needs some form of 'Quality of Service', in order to ensure the quality of the service can be what the end-user expects. The requirements on the network to support Quality of Service differs from service to service. For example a telephony service will have more stringent quality of service requirements then a more 'general' Internet access service (browsing websites). Usually the following "Quality of Service parameters" are used to express how the network can support a certain quality to a service (telephony, video, or internet):

Delay/Delay Variation:

Services that have to be delivered almost 'real-time' (like the VoIP telephony service) often have more stringent requirements towards the delay and variation in delay than Non Real-time services (like file download). An on demand video service is less susceptible to delay, since often the video stream is 'buffered' for several seconds in the player in order to be able to 'flatten out' hick-ups in the network.

Packet loss:

A low packet loss is usually more important for services that cannot retransmit their information when it was in error. This is the case with most of the 'real-time' services which do not have the time to do this (if they retransmit an erroneous packet the retransmission will come most likely to late to use, since that video or audio segment has already passed).

In order to make sure that delay (variation) *and* packet loss requirements can be fulfilled for specific traffic flows under network congestion conditions, most networks implement certain "Quality of Service mechanisms". These mechanisms consist of implementing the tagging (marking) of certain types of traffic (e.g. voice- or internet-traffic) and using this to serve e.g. voice traffic with a higher priority than the internet traffic (which has to wait a bit longer than the voice-traffic to be transmitted).

Network Security Requirements:

Security in general is important for services that carry some privacy sensitive information (like the content of a telephone conversation or transaction information of home banking) or content that has a certain commercial value (like on demand movies). These services need some level of protection that only the intended recipient(s) can receive and use this information. This type of security is usually implemented on a 'higher level' than by the network itself, often this is done by the (service related) client and server (like a software player or set top box for the on demand video). *Network* level security consists of more general security functions like some sort of "traffic separation" between different users by means of port based traffic switching or Virtual LANs (VLAN)[1] and/or the possibility to 'bulk encrypt" all the traffic between user and central office. The network encryption function is often used by broadband wireless systems (like wireless LAN and Wireless Local Loop) to provide a network security that is 'equivalent' to point-point broadband wire line infrastructures like the telephony network (as a signal sent over the air can be easily

[1] On the protocol -layer (Layer 3 and higher) there are more functions available, which will not be covered here.

received by others, while a signal sent over the dedicated telephony cannot be received unless an explicit physical ‘tap’ is placed). Also *shared* wire line networks use this (like cable networks and passive optical networks) as neighbours potentially can receive each others traffic (since they are physically connected to the same ‘shared’ infrastructure).

The segregation of traffic function is often used to make sure that traffic of customers served by one Service Provider do not interfere with the traffic generated by customers of a different Service Provider and is especially important for “open broadband networks” which give access multiple Service Providers.

Network Availability Requirements:

Most current internet based services have low availability requirements as they are often free of charge and do not perform ‘critical’ services. However this is changing now since the existing analogue services like regular telephony and broadcast TV also will be offered over the Internet (Voice over IP, Digital TV over IP) via the different types of broadband networks. For these services often the user will have to pay an explicit fee and has an expectation that the availability is similar as the service that was offered in the ‘traditional’ way. For telephony this might even go as far that even after a power failure, the telephony service should remain active (‘lifeline’ functionality) as this functionality is offered by KPN for the regular telephony service (by remotely powering the telephone from the Central Office, which has a emergency power supply).

In the following paragraphs we use these requirements to investigate the triple play services

2.2 Personal communication: telephony, video telephony and instant messaging

Investigating the bandwidth/speed requirements towards the capacity of the network

When looking at the requirements telephony has regarding bandwidth, it is rather small compared to other services. When looking at the improvement of the audio codec's, one can even see that the data rate needed for a voice conversation with the same quality has reduced slightly over the years. Alternatively, when using the same 64 kbit/s (ISDN) speeds for a voice call with newer codec's a higher voice quality is achieved. E.g. the audio codec of a popular new VoIP client called "Skype" can use a factor 2 less than the regular 64kbit/s (if there is not enough bandwidth), but can increase its code rate if a broadband connection is available and achieve better voice quality than PSTN [10]. Also the VoIP standard 'SIP'[2] can include both low bitrate (GSM-quality) and high bitrate (high audio quality) [3]. Videophony will also start to gain more popularity and more professional use will start to become main stream. With this the video-quality will increase from small screen video to full screen videophony. In case of use by healthcare professionals a High Definition (HD) quality Videophony connection might be needed (e.g. to perform remote consultation by a doctor).

Personal communications is changing gradually and next to instant messaging (which does not require much bandwidth) it can be expected that in the coming years video-telephony will become more popular.

This evolution will be the main driver behind a higher bandwidth requirement for the personal communication service.[4] An indication on how these services might evolve the coming years is depicted in the following figure.

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2 SIP stands for 'Session Initiation Protocol' and is a standardised solution for VoIP (ITU-standard).

3 The Skype audio codec passes all frequencies between 50 -8.000 Hz, which is more than the normal telephone network (PSTN) will pass in the Netherlands (300- 3.100 Hz) and how speech quality over the ISDN is realised (often in 3.1kHz 'basic audio mode' since most calls terminate in PSTN). A newer ITU codec specifies coding from 50-7.000 Hz (G.722/G.725) which achieves similar quality as Skype's proprietary audio codec and can be used in the VoIP SIP –standard.. Frequencies present in the human voice range from 82Hz to 20.000 Hz.

4 Vonage, a big Voice over IP telephony provider in the US will start offering video-telephony to all its customers begin 2005. Also the more 'free' computer based client Skype is developing videoconferencing.

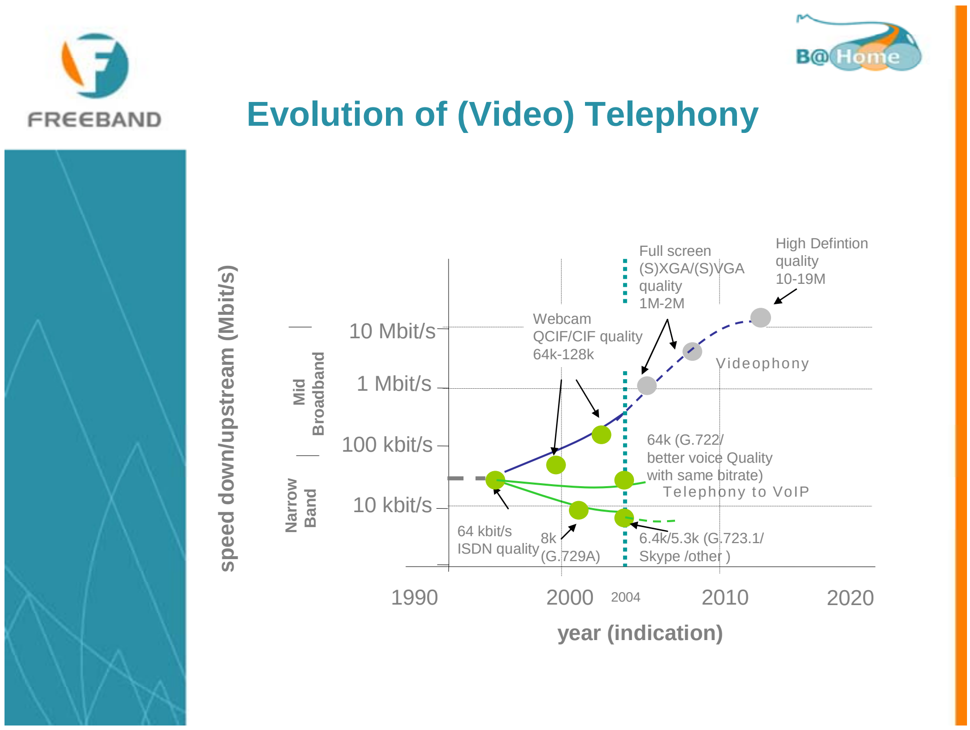

Figure 1. The evolution of telephony and video-telephone services[5]

Investigating the network quality, security and availability requirements

Currently, most (free) Voice over IP systems use the internet to interconnect and thus are dependent on the quality of this network. This sometimes means that the voice calls are dropped or interrupted when congestion occurs in the internet. This is unacceptable when VoIP –based telephony is used as an alternative to PSTN or ISDN. Some VoIP based telephony service providers are already making sure that their VoIP-traffic is handled differently, by making explicit arrangements with broadband network providers that their VoIP-traffic is assigned a higher priority then regular Internet traffic. Service Providers might even arrange that the voice traffic is sent in a separate channel over the broadband network[6].

Regarding security it can be said that the telephone conversation should remain private between parties, most VoIP devices/clients provide ways to encrypt the phone call. However this should be standardised to ensure interoperability and ways for law-enforcement to still tap in to a VoIP conversation when needed.

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5 The Traffic Direction of personal communication services is usually both receiving and sending (voice, video) traffic, and therefore has a more symmetric traffic profile. The traffic generated by voice services will be constant or variable bit rate depending on the audio/video codec used (e.g. when silence suppression is used in an audio codec, no traffic will be generated in one direction when the audio signal is below a certain threshold). Regarding the Traffic Duplication the traditional way of telephony is of course point-point, however with conferencing facilities being build in to the VoIP clients, this will somewhat change to multipoint-multipoint.

6 In the Netherlands the operator Scarlet offers Voice over IP based telephony to DSL customers connected to the BBNED DSL network, in this network BBNED makes sure that the VoIP packets are transmitted in a separate channel, which is independent of the internet traffic.

This last issue already poses a problem as Skype by default encrypts all phone calls using its own proprietary encryption method, making it difficult for law-enforcement to tap these calls.

When the end-user fully switches over to VoIP-based telephony he will lose the lifeline functionality of the regular telephone line as provided by most incumbents[7] (who remotely powers the telephone from the central office in case of power outage). Although for many consumers this might not be a big concern, for larger corporations it might. The notion that the VoIP-user has a backup by means of cellular phone might not hold true in case of a citywide power outage, where the cellular base stations also will be out of power. Also depending on the arrangements of the VoIP service provider the calling of emergency services might be different[8].

In general it can be said that when VoIP based telephony becomes a real substitute for the regular telephony service the requirement regarding quality and availability of the underlying broadband network will increase.

2.3 Broadcast radio/TV and streaming video/audio on demand

Investigating the bandwidth/speed requirements towards the capacity of the network

A service like broadcast TV poses a higher requirement on the downstream than on the upstream capacity of a broadband network (asymmetric service). TV broadcasts over IP will use “several Mbit/s” depending on the quality, and might need more than 10 Mbit/s if High Definition Television (HDTV) is used or multiple people in one household start watching to different regular TV/video streams over one broadband connection. Broadcast TV can be transported efficiently by sending the live TV stream in such a way over the network than only once the capacity is needed in the central part of the network, irrespective of the number of users watching (this is called ‘multicast’). This type of network transport can support a stream which will be able to reach all interested users, without the need for individual capacity requirements per user in the central part of the network.

On demand video usually is an individual service to a user who at a certain moment selects a specific video stream to watch. From a network capacity point of view, this means that each on demand video stream is individually transmitted (unicast) to a user and will need its own bandwidth reserved on the network. As a consequence, on demand video will have a higher impact on the capacity of the network when it becomes popular and more users will start using it more frequently.

7 Like incumbent operator KPN in the Netherlands

8 In the U.S. for example a subscriber might not be able to call 911, or when made possible the 911 call will be transferred to a different destination: the so called Public Safety Answering Point (PSAP), this emergency point might not have your address, as is often possible by means of regular caller id on the regular phonenetwork.

Depending on the coding used for the video (or audio) content, the typical stream behaves like a Constant Bitrate (CBR) (fixed code rate of a codec) or a Variable Bitrate (VBR) source. Most codec's are capable nowadays to support variable (VBR) encoding of the video content, allow more efficient use of the needed bandwidth. Regarding the quality we see that both video and audio are undergoing a change in quality of the picture/sound. The different types of video and audio quality are shown in the following figure.

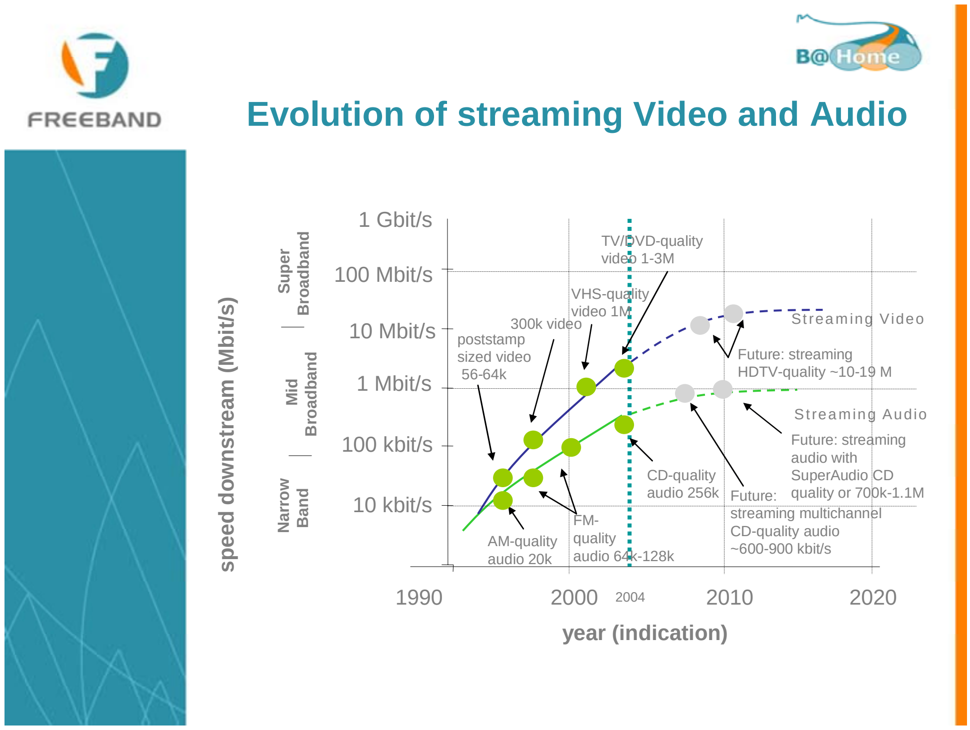

Figure 2. The evolution of streaming Video and Audio services

When looking at the growth of video services (both on demand video and broadcast TV) it can be concluded that these will evolve with higher quality as main bandwidth driver, growing from mid-broadband speeds (<10 Mbit/s) (standard TV quality) as a requirement to super-broadband speeds (>10 Mbit/s) (High Definition TV).

Also audio streams will continue to grow in quality; however this will stay in the mid-broadband speed range.

For the video and audio service specifically there seems a trend that after Super Audio CD and HDTV the 'maximum' quality that the end-user will need for this service is reached[9]. If any increase in quality might still be needed this will most likely be achieved by the innovation of better codec's with which one can

[9] For television a long term development is the change from 2D projection of the video to 3D.

obtain a higher quality with the same bit rate. This trend explains the flattening of the capacity growth curve.

Investigating the network quality, security and availability requirements

The initial streaming on demand services where almost all free to view and destined for viewing on a webpage on the computer monitor. As now real commercial on demand video portals are starting to materialise (like the Moviestream service of Planet Internet, the Filmportal service of Casema or the independent online movie-service of Maxx-xs) the need for service providers to make sure that the video stream is delivered without interruption (low packet loss) becomes more important. This is due to the fact the on demand video services are evolving and become a real alternative for renting a DVD. The consumer will expect that the quality of this service is comparable with that of a ‘normal' rented DVD. In order to guarantee this quality, network QoS mechanisms should be in place. A medium to high availability of the network should also be needed not to frustrate customers with service ‘blackout' periods.

Network based security is not needed for these services as usually in the software client or set top box on ‘application level' the security is handled to protect the content from being seen by (not paying) other customers irrespective of the underlying transport network (network independent security).

2.4 Internet access services: teleworking, gaming and file sharing

When looking at the requirements of the Internet-access service, one can say that the *end-user services* (that are transported over this Internet access) are the drivers behind more bandwidth and other requirements towards the broadband network (not the generic Internet access itself). Here the network requirements of the services such as teleworking, gaming and file sharing are investigated.

Investigating the bandwidth/speed requirements towards the capacity of the network

Services like gaming and teleworking will be more symmetrical in nature although from time to time with certain (one-way) downloads this behaviour might temporarily change. The bandwidth requirement of teleworking is changing rapidly from basic (web based) email access to full fledged corporate LAN access from home.

> This will mean that a teleworker will have to be able to access online applications and files with (peak) speeds of 10 Mbit/s or even 100 Mbit/s, just as he would be able on his corporate LAN[10].

[10] It should be mentioned though that this does not mean this capacity should be always reserved for each teleworker, as his average (sustained) used bandwidth will be lower.

Nowadays most businesses have 'VPN-access' to their LANs in place for their teleworker employees, where speeds of several Mbit/s are very common and needed for efficient file transfer and email attachment download. An indication on how teleworking and gaming might evolve in the coming years is shown in the following figure.

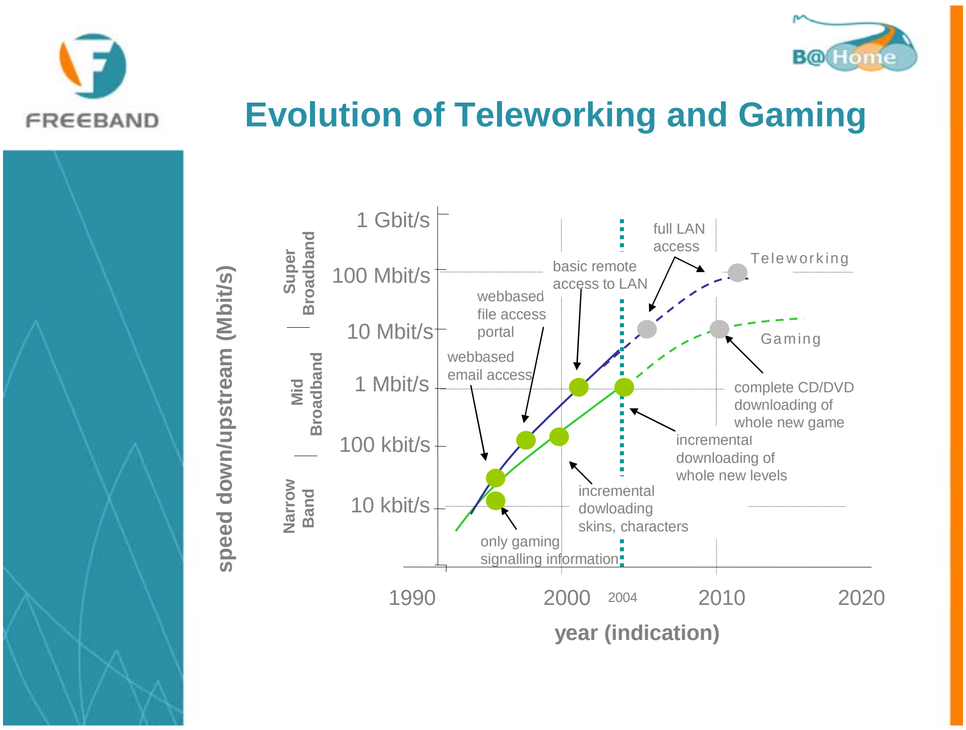

Figure 3. Indication of how teleworking and gaming services might evolve

From this figure it can be seen that the bandwidth requirement of teleworking will shift from 'dial up' speeds (Narrowband) to mid-broadband speeds (10 Mbit/s). It is even foreseeable that in 2012 also 100 Mbit/s remote LAN access will start to become a requirement as some corporate applications will be centrally run from the server and not from the local computer. Gaming will grow from lower to higher mid-broadband speeds evolving from simple gaming itself (where the game is purchased separately on a DVD) to partial level/ skin downloads and complete online purchase/download. As soon as complete games will be offered online to be downloaded this will also drive the requirements of gaming from mid-broadband towards super-broadband speeds for a timely download of the whole game (typically CD to DVD sized application). This evolution in effect changes / broadens the scope of the classic gaming service (where via online gaming server people could interconnect their pre-installed games) to an official online game download and multiplayer service.

An interesting Internet based application is file sharing. Many users swap files over the Internet, by using so called 'peer to peer' file sharing clients (like Kazaa, Bittorrent and Exeem). When looking at the bandwidth requirement of this service, it can be said that this depends on how timely the user want to receive a download. Currently file sharing clients vary between taking the maximum bandwidth that is available on the broadband connection to very slow (100 kbit/s) connection, the latter situation can occur because the remote end does not have more upload capacity available. Over the past year the use of file sharing clients has changed from just downloading single songs to downloading complete audio-CD, often stored (ripped) in to a more efficient format (e.g. mp3 or windows media). This change was possible because the network capacity of most cable and DSL lines was upgraded to higher speeds, which enabled users to download a complete audio CD [11] within 7-70 minutes (assuming a broadband connection between file sharing client and server of 1 Mbit/s-100kbit/s). A file sharing 'service' is actually a 'self evolving' service, which follows the growth of the network capacity, just using the bandwidth of the network when it becomes available to be able to download more and higher quality content in a shorter download time. When a complete download of a DVD movie or game[12] can be realised within 7 to 70 minutes over upgraded broadband networks, the popularity of this type of download will increase amongst end-users thus changing the way the service is used. This is shown in the following figure, it should be noted that this figures gives an indication of the behaviour of file sharing for 'example' download times of 7, 70 minutes and 12 hours.

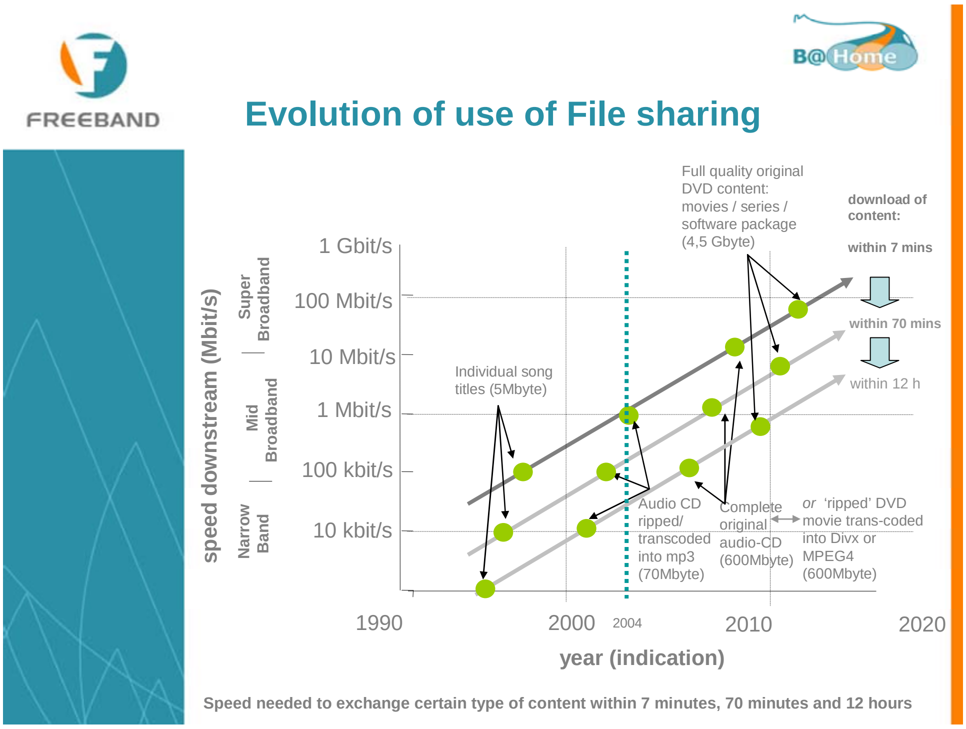

Figure 4. The evolution of the file sharing service

[11] Assumed here is that the audio CD is ripped in mp3 format taking up a total of 70Mbytes for 70 minutes of playing time.
[12] Assumed here is that the complete DVD movies is 4,5 Gbyte

It can be concluded that for teleworking, gaming and file sharing it is the change in *quality of the service*, together with *broadening in scope* of the service which will drive the increased need in bandwidth.

Investigating the network quality, security and availability requirements

When teleworking is more used as a full equivalent to working in the corporate environment with speeds of 10 to 100 Mbit/s it can be predicted that the underlying network quality and availability will become more important for an end-user (high network quality and availability requirements). Security of the teleworking data is important but often handled by encryption done by small application installed on the remote (telework) computer[13]. Some large corporations might also favour broadband networks that can provide some security on a (lower) network level[14].

For gaming the quality of the network is of utmost importance, especially a low delay is needed (in order to signal the change in position of the character in the game to the other online participants in the game).

The file sharing service is in essence a file download service that can download certain content from multiple sources, and has lower requirements towards network quality (delay and/or packet loss) and availability; it usually has time enough to ask for retransmission of lost information and does not have to deliver the requested content 'real time'.

2.5 Summary of service requirements

Bandwidth

The triple play services that will drive the requirement for more bandwidth are the broadcastTV/on demand video service due to increase in quality from standard TV to High Definition TV and Internet based teleworking service evolving from just simple email access to full corporate LAN access.

The file sharing service will also self evolve when more network capacity comes available and has the capability to consume 100 Mbit/s in order to quickly download the contents of a complete DVD. Another factor is that within a household more people will start to use the same broadband connection (from just 1 person behind a PC to several family members: one behind the PC, the other watching an on demand video and the third teleworking).

[13] Encryption is often done by Virtual Private Network (VPN) software which is needed to log into the IP-domein of the corporate LAN.

[14] For example on Ethernet networks using VLANs and on ATM networks using a separate Virtual Channel to separate the Internet traffic from the Teleworking traffic

These developments regarding higher quality and more concurrent use will drive the overall bandwidth requirement of the services investigated here from mid-broadband (<10 Mbit/s) to super-broadband speeds (10 Mbit/s-1 Gbit/s).

This is shown in the following figure.

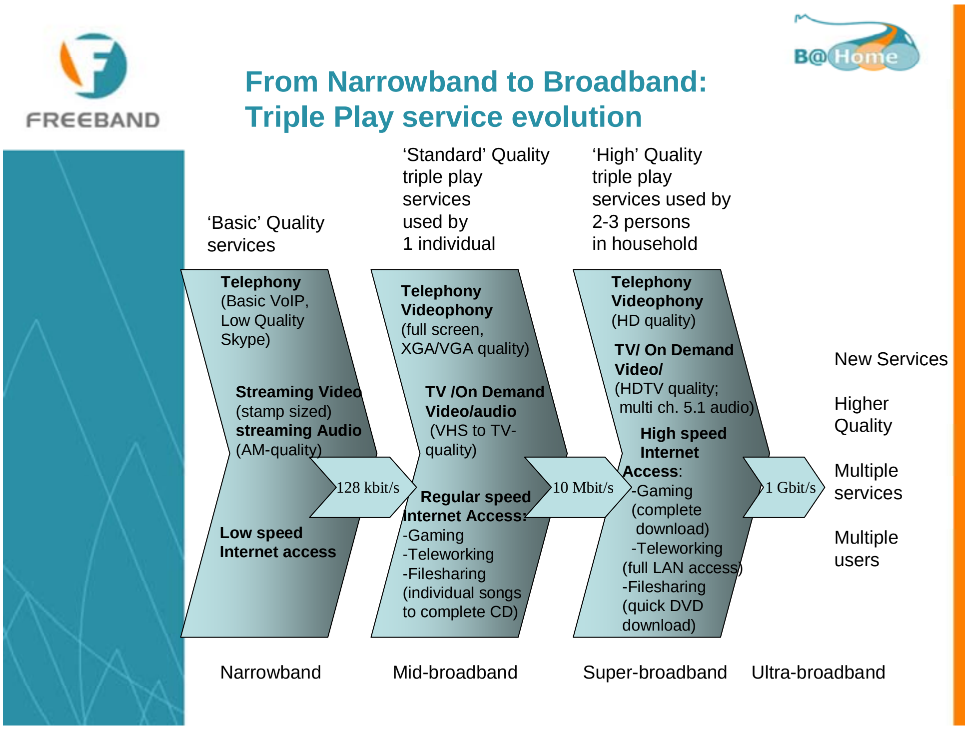

Figure 5. The triple play service evolution regarding bandwidth requirement

Quality, Security and Availability

Services that will be key drivers behind higher network requirements regarding quality (e.g. being able to give priority to certain types of traffic) are the online gaming services together with the VoIP-based telephone services that are offered as an alternative to normal telephony subscriptions. Security demands often will be addressed by the application involved and will apply certain encryption to keep the communication safe. However since most (software) encryption systems in the end can be compromised, certain services might require an extra physical type of security provided by the network itself (like separating the traffic from internet traffic, offering a dedicated 'leased line' type of service). A high network availability of broadband network will be required by services such as the VoIP based telephony service[15] which might need 'life line' functionalities. Also 'paid for' services like on demand video will require a

[15] like calling 112 with the VoIP telephony service, but also telephony related services like the signalling of burglar/fire alarm or a emergency medical video-telephony call by an home-patent.

reasonably high availability as an outage during the ordered movie will not be accepted by the customer. Availability comparable to the ‘Internet access service’ is for these cases unacceptable. In the next table these requirements are summarized.

Triple Play Services	**Bandwidth Requirements:**	**Network QoS requirements:**	**Network Security Requirements:**	**Network Availability requirements:**
Personal comms:				
Instant messaging	**Narrowband to Mid-broadband** (from just text messaging to multimedia messaging)	**Lower requirements**	**Lower requirements**	**Lower requirements**
Telephony, Voice over IP	**Narrowband** basic voice telephony	**High requirements** Very sensitive for delay, delay variation and packet loss.	**Medium requirements** traffic separation on network level to separate voice from internet traffic is advisable	**High requirements** the traditional lifeline function of tradition telephony should be delivered
Video-telephony	**Narrowband to Mid-broadband** from low to high resolution video conferencing			
AV Entertainment: Broadcast TV	**Mid-broadband Asymmetric** Constant to Variable bitrate Broadcast TV channels can be efficiently Multicasted (PM)	**Lower requirements**: Less sensitive for absolute delay: (client usually buffers stream before playing) More sensitive for Packet loss	**Lower requirements** No network layer security requirements Copyright security needed but not implemented by network	**Medium to High requirements** Users expect same quality of cable TV for Broadcast TV over IP
On Demand Video	Due to unique on demand feature mostly Unicast (PP)			**Low to High requirements** User might be able to wait for start of stream. Once commenced it should have high availability
Internet access:				
Games	**Narrowband to Mid-broadband** (game position signalling to download of gaming level/environment) **Symmetric** (game signalling) Variable bitrate to bursts Multipoint to Multipoint (MM)	**Higher requirements** Very sensitive for delay Sensitive for packet loss	**Lower requirements** No network layer security requirements	**Medium requirements** Gaming is often free, lower availability of gaming servers is within expectation of customer News reading can be postponed
Teleworking	**Mid-broadband to Super-broadband** Teleworking can range from simple access to email, with basic file access, to real-time LAN access with all applications and facilities	**Higher requirements** remote access to LAN resources should have minimal delay to copy work desktop experience	**Higher requirements** Next to Layer 3 security might Layer 2 network security be an option for secure teleworking	**High requirements** During teleworking hours the employee must have access to all teleworking facilities
File sharing	**Mid-broadband to Super-broadband to Ultra-broadband** This service can evolve from downloading simple songs to complete contents of DVD, where the time it takes to download this will change.	**Lower requirements** As it is not a real time service, it has usually time to recover from lost data and ask for retransmission	**Lower requirements** Copyright security might be needed but not implemented by network	**Low requirements** As file sharing clients usually work 'in the background' a (temporary) network outage will not really influence greatly performance

3 Broadband infrastructures and their support for triple play services

In the previous chapter the requirements that triple play services impose on the access network are discussed in terms of bandwidth requirements and requirements regarding network QoS, network security and network availability.

In this chapter we investigate what the characteristics of the different types of broadband access networks are in relation to the requirements mentioned above.

3.1 Telephone network

Bandwidth characteristics

The capacity growth of the telephone network has been investigated in [1] (“Breedbanddiensten: de gebruikers- en netwerkeisen” TNO-Telecom) and updated in this paper to accommodate new developments regarding DSL technologies. ADSL is currently the most used transmission technology in the telephone network supporting 8-10 Mbit/s[16] downstream.

However newer DSL-technologies have emerged: ADSL2+ and VDSL, and these will start to be used to offer higher speeds[17]. Using ADSL2 has the advantage that a longer loop length can be realised compared with ADSL. When using ADSL2+ (plus) a higher downstream data rate can be realised by using more spectrum (from 1.1 MHz to 2.2 Mhz). It should be noted though that ADSL2+ and VDSL can only realize the higher speeds over short distances, an indication of this is given in the following table.

[16] ADSL can support a maximum 8 Mbit/s downstream, but there are already 10 Mbit/s downstream ADSL-modems

[17] ADSL2+ will be offered in the Netherlands in 2005 to businesses and consumers by InterNLnet (ISP) in cooperation with Surfnet and BBNed (DSL network owner). KPN is also considering the introduction of ADSL2+.

Table 1. Typical VDSL and ADSL2+ speeds and distance (DSL Forum and Aware) [7] [8]

VDSL downstream speed (Mbit/s)	**Maximum distance (meters)**
12.96 - 13.8	1500
25.92 - 27.6	1000
51.84 - 55.2	300
ADSL2+ down (Mbit/s)	**Maximum distance (meters)**
18 Mbit/s	1500
25 Mbit/s	900

When looking towards the future one can see that the VDSL2-standard (currently under development) can provide data rates of 50-100 Mbit/s downstream and upstream[18], however this (like with VDSL) will be only over short distances and the actual performance will be heavily dependent on the number of other DSL-users already on the network. In order to be able to offer these speeds to most customers on the network more fibre will need to be introduced from central office towards the customer[19].

In the following figure the introduction of the different technologies is depicted. In this figure the introduction rate of different types of modems in the telephone network (e.g. the analogue modem, ISDN modem and DSL-modems) and the market availability of a certain configured maximum DSL-speeds has been used to obtain an indication of the capacity growth of the telephone network. This growth is partially influenced by the availability of a certain DSL-transmission capacity and on the other hand by the operator determining the maximum speed it will offer (product speed).

[18] VDSL2 is currently under review by the ITU for standardisation. The higher speeds can be realised by using more spectrum up to 30 MHz (instead of 12 MHz with regular VDSL). There are no practical implementation yet to prove this speeds can be realised on normal scale in operational telephone networks. Performance will depend on amount of cross-talk. Dynamic Spectum Management techniques may be required to reach the high performances up to 100 Mbit/s. DSM-techniques minimise cross-talk by compensating the crosstalk signals originating form other DSL-users, however this will mean that (competing) DSL-operators will need to cooperate in implementing this technique together in their DSL-equipment.

[19] With the VDSL DSLAM in a cabinet on street level

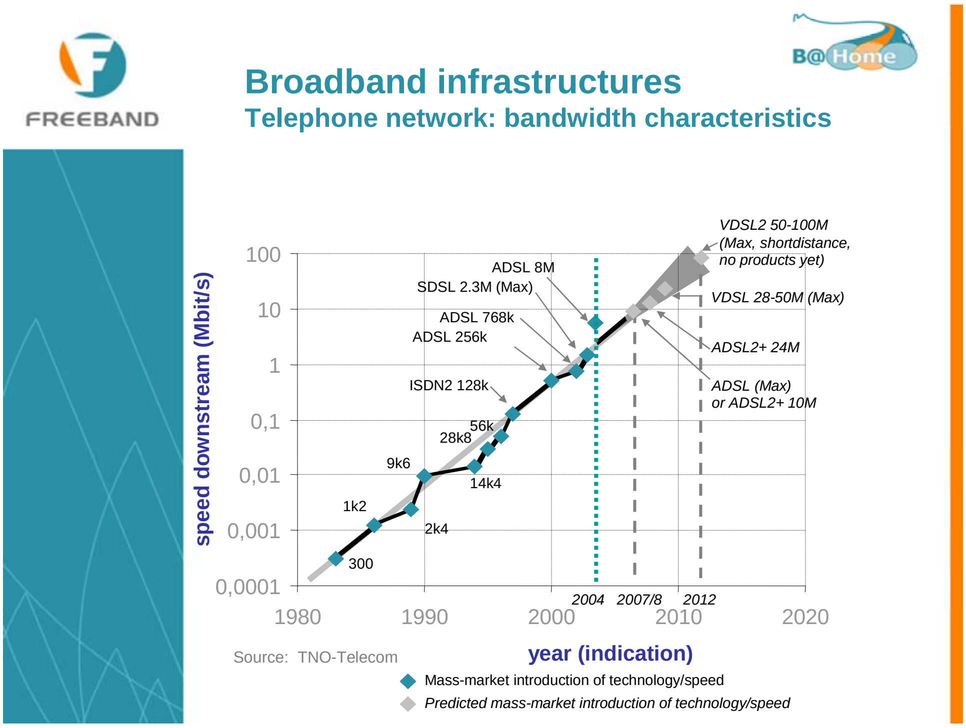

Figure 6. The growth of the telephone network capacity

It can be concluded that with the new DSL technologies the bandwidth of the telephone network can be upgraded from the current *mid-broadband* speeds (< 10 Mbit/s) to the lower end of *super-broadband* speeds (10-50-100 Mbit/s)[20]. This will make the introduction of more fibre into the access network necessary in order to compensate for the shorter reach of newer DSL-technologies.

Network QoS characteristics

Regarding packet loss it can be said since DSL is a fixed wire line access technology it will usually have high network availability and thus packet loss due to network failures will be low. Packet loss due to explicit network decisions to drop certain traffic (using prioritisation mechanisms) is dependent on how prioritisation is handled inside the network, and a more likely cause.

Most of the current DSL-networks use ATM as their main transport for Internet (IP)-traffic. The traffic segregation and priority features of ATM[21] haven't been used much, but are now starting to be used for

[20] When looking at traffic direction it can be seen that with ADSL the telephone network can support mostly asymmetric services, but with SDSL, which is currently offered in most areas, symmetric services can also be supported. VDSL can be configured to accommodate both asymmetric and symmetric service. Since each customer has an individual DSL line towards the CO/DSLAM, the bandwidth reserved for the customer in this (access) part of the network is dedicated and not (yet) oversubscribed, the aggregation of the traffic of multiple users is done in the Central Office and onwards in the core network.

[21] E.g. by using the ATM Virtual Paths (VP's) and/or Virtual Circuit (VC's) to segregate certain types of traffic from each other and giving these traffic flows different priority in the network

giving telephony-traffic priority over other traffic. Telephony over the DSL network is often called *'Voice over DSL'*. This does imply that some cooperation between the telephony provider and network provider is in place, as the voice traffic should be transported in a separate 'channel' (ATM Virtual Connection) which both parties have to decide upon. Therefore Voice over DSL providers are usually associated with one or more network providers, an example is Scarlet Voice over DSL (using the BBNED DSL network).

A *'Voice over IP' service provider* that offers telephony straight over the internet cannot use this type of QoS[22], but on the other hand *can* provide the telephony service without any special arrangements with networks providers. An example in the Netherlands of an Internet telephony provider is Rits-Telecom, who offers VoIP telephony to all customers with a broadband connection. Rits-Telecom also has some direct arrangements with FttH-network providers.

Network Security characteristics

End to end security is often realised by end-user applications (VPN software and the applications themselves), but DSL networks can use some functions[23] to make sure that the traffic of the subscribers of one Internet Service Provider (ISP) will not enter into the IP-domain of the other.

In general it can be remarked that the dedicated copper wire connection each subscriber has with the Central Office could be considered as a basic level of security compared to shared broadband (cable or radio) connections.

The overview of the DSL-network and its support for these requirements is shown in the following figure.

[22] An Voice over IP service provider might in the future use the priority features of the IP layer, but this will still need to be implemented end to end over the network equipment of all involved access networks providers.
[23] ATM traffic separation functions

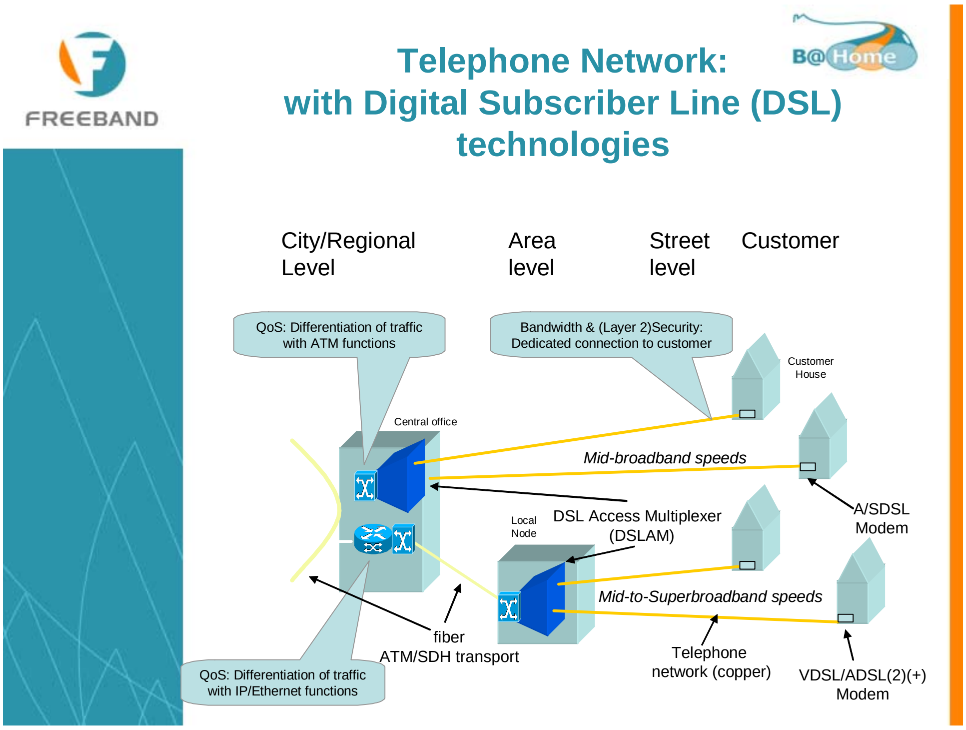

Figure 7. The telephone network with DSL technology and its support for triple play requirements

Network Availability characteristics

Availability is dependent on many factors, the frequency of the failures (Mean Time Between Failures (MTBF)) of the active equipment and passive network and the ability of the network operator to repair this as soon as possible (Mean Time Between Repair (MTBR)). These figures are seldom published; however in general one can make the remark that the availability of the passive access network is quite high, since it's the same network as used for the analogue/ISDN telephone service. One important factor in the availability is the way a network copes with a power-outage. With DSL the customer will need a DSL-modem powered from within the home, so a power failure will result in an outage of the broadband network connection (while the regular analogue telephone connection will be remote powered from the central office with power backup).

Certain Voice over DSL service provider try to solve this problem by installing Voice over DSL-modems at the customer premises with an option to connect the 'old' analogue telephone connection, when power fails the customer can still call over the (lifeline) analogue telephone connection[24] (however this does mean the user has to retain his old analogue telephone connection). Battery backup for Voice over IP and DSL-modem is another option, especially popular in the U.S., but in Europe not (yet) often offered by service provider in combination with their equipment.

[24] Voice over DSL provider Solcon in the Netherlands provides such a Voice over DSL-modem.

But next to the home equipment the central office DSL-equipment will need a power-backup system in place in order to be able to continue the service in case of power outage. Currently in the Netherlands it is not common practice to have an uninterruptible power supply (UPS) in place for the DSL-equipment (DSLAMs). If the subscriber uses the Voice over DSL or Voice over IP, his telephone service will stop in case of power outage (no ‘lifeline’ functionality).

3.2 Cable network

Bandwidth characteristics

For cable networks in the Netherlands the introduction of the first proprietary cable modems was between 1995-1996, these modems realised low speeds (~100kbit/s), therefore cable operators soon implemented second generation and third generation cable modems who were more standard compliant and had higher data rates (27-38 Mbit/s). Currently all the new cable modems that are installed are EuroDocsis compliant cable modems. These cable modems offer good QoS service and *channel data rate* between 38-52 Mbit/s, the cable operator determines how many users share this channel capacity. The dynamics in the broadband market will most likely result in cable operators increasing the number of cable modem channels to increase the bandwidth per user (fewer users per channel) together with other upgrades to the network.
The evolution of the cable network has also been investigated in [4] (“Ontwikkeling van diensten en kabelinfrastructuur”). The introduction of the different cable modem technologies is shown in the following figure.

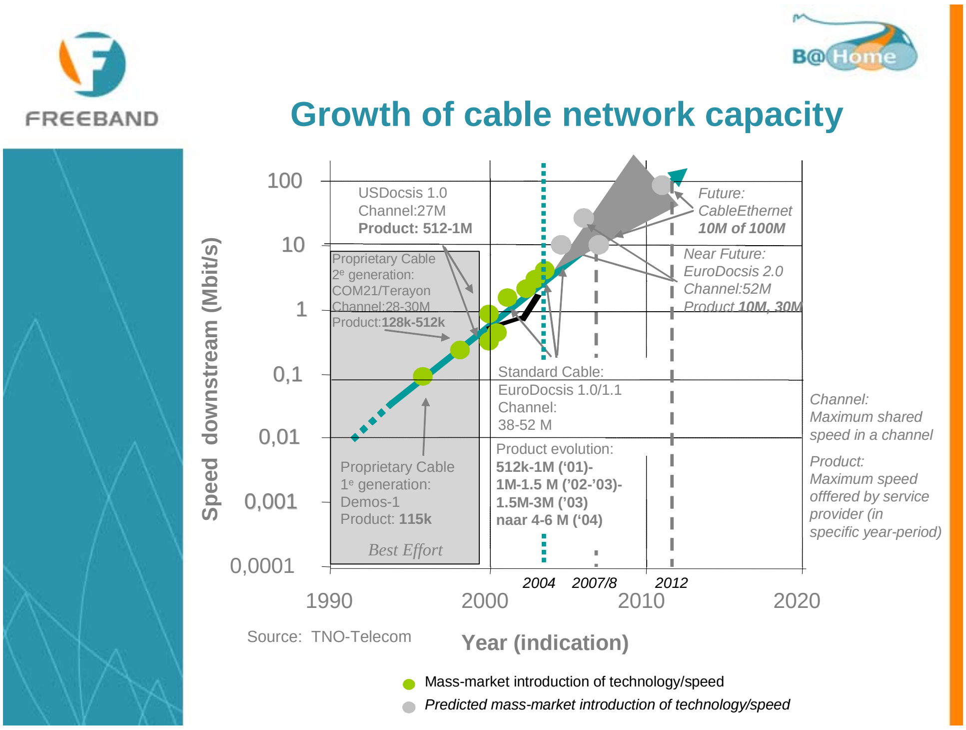

Figure 8.. The growth of the cable network capacity

This figure shows that the cable network will be able to support the current mid-broadband speeds (<10 Mbit/s) to super-broadband speeds (10-100 Mbit/s, and possibly >100 Mbit/s) to the end-user[25] when using new transmission technologies like EuroDocsis in combination with upgrading[26] of the Hybrid Fibre Coax infrastructure.

When looking towards the distant future it can be said that *technically* a coax cable can support speeds higher than 1 Gbit/s, if used as a *dedicated* connection to each customer (not in the tree and branch topology as the cable infrastructure currently is deployed) with all the analogue TV-channels digitized and transported over the (ultra-broadband) IP-stream.

In the beginning of the roll out of the first (proprietary) cable modems the expectation of the customer regarding the availability of the peak data rate was higher than the network could deliver, but nowadays most cable operators take extra care in performing correct network dimensioning and dynamically change

25 Regarding the Traffic Direction it can be mentioned that current cable modems support more asymmetric speeds than symmetric speeds (more download than upload). However with newer cable modems following the EuroDocsis 2.0 standard (or higher) the cable network will be able to support more symmetric speeds (downstream 52 Mbit/s will be possible and upstream 30 Mbit/s). The Cable Ethernet modems will be able to support symmetric 10 to 100 Mbit/s.

26 For cable networks next to more fiber in the access network, capacity can be increased by decreasing the number of subscribers in a segment, adapting higher modulation methods and using higher frequency band for transmitting the data.

network topology to accommodate the (gradual) change in bandwidth usage and performance expectation of its customers[27].

Network QoS characteristics

With the newer EuroDocsis modems cable operators are able to provide several levels of quality of service[28]. In support of cable operators who want to rollout triple play, the international Cable Labs consortium has defined a standard architecture (PacketCable) how to implement a cable network to support both internet and telephony service (next to the broadcast TV-service) with good quality of service.

Network Security characteristics

As it is a shared network downstream traffic of a subscriber can be received by neighbours (in the same segment of a cable network). However the EuroDocsis 1.1 (and higher) modems support encryption and authentication of the subscriber traffic between cable modem and CMTS in the 'Baseline Privacy Interface' (BPI) or BPI+ specification.

[27] Since the cable network is a shared medium the oversubscribing can already take place in the access part of the network next to the core network (after the CMTS onwards to the service providers domains and the internet). This allows cable networks to offer higher 'peak' data rates (up to the shared data rate of a cable modem channel), to users when the network is not congested (not busy), while sharing the capacity of this channel among multiple users. Because of this 'sharing' In the busy hours of the network the performance may drop to a much lower (sustained) data rate, if this is not correctly management, this performance drop can be too high and noticed by the end-user as a 'bad service'.

[28] Starting from EuroDocsis 1.1 and higher the following quality of service function are available:

- Best Effort: ATM like UBR-behaviour, default service (primary service flow)
- non-Real Time Polling on fixed time periods polling of traffic: e.g. massive FTP
- Real Time Polling on fixed time periods polling of traffic of variable length, e.g. VBR MPEG 2

Unsolicited Grant (with Activity Detection) more CBR behaviour timeslots of fixed length on fixed time slots dynamically reserved for e.g. VoIP, Activity Detection for e.g. Silence Suppression in VoIP

Network Availability characteristics

The same factors involved in network availability as mentioned in the 'network availability paragraph' for the telephone network (DSL) is applicable for cable as another fixed wire line broadband network. There is one difference, with a shared network topology the cable network is more susceptible to interference generated in the upstream frequency band generated by one subscriber interfering with the communication capabilities of the (neighbouring) other subscriber (ingress-noise) on the same (shared) coax cable, while with DSL there is interference in both the down- and upstream direction due to signals of neighbouring cables (cross-talk). In practice network operators have several ways to limit these noise problems.

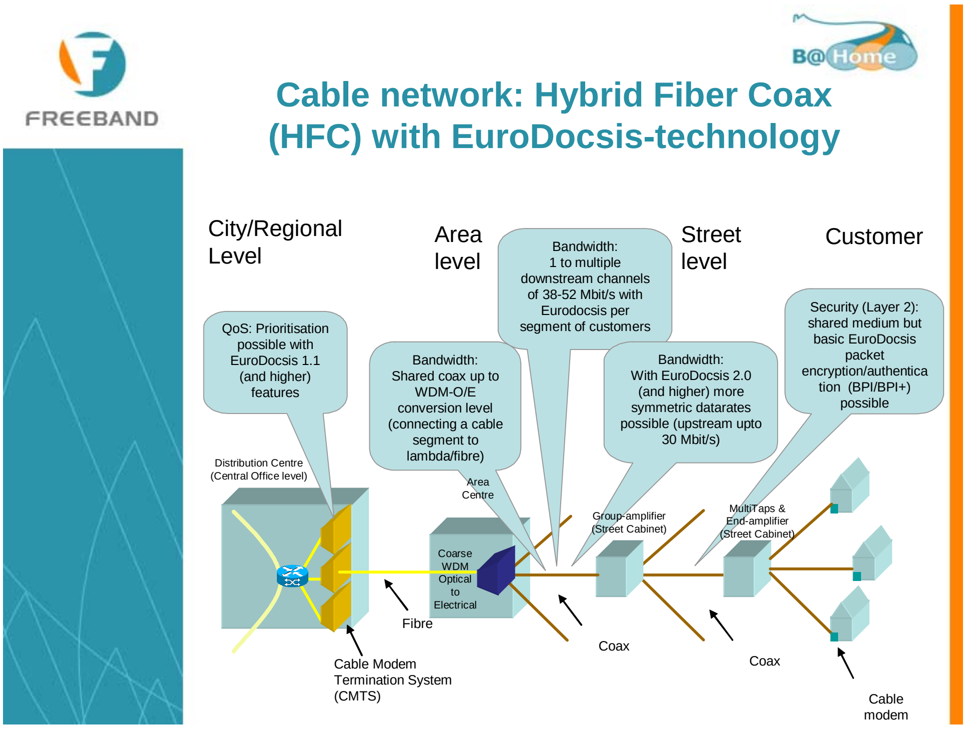

Figure 9. The cable network with EuroDocsis technology and its support for triple play requirements

3.3 Fixed Wireless Access

Bandwidth characteristics

The end-user speed to be offered by Fixed Wireless Access techniques depends on several factors. FWA techniques are often used in point-to-multipoint mode were multiple users share the same bandwidth. They also use different types of bandwidth for a 'channel'[29] (a typical bandwidth is usually associated with this), depend on how large the channel bandwidth is, the data rate can be higher or lower.

There are different types of FWA systems, often also referred to as 'Wireless Local Loop' (WLL). In the U.S. these are also referred to as 'Local Multipoint Distribution System' (LMDS) (often using the 26 GHz frequency range) and 'Multichannel Multipoint Distribution System' (MMDS) (often using the lover 2.6 and 3.5 GHz frequency range). Current WLL systems often use proprietary transmission technologies, however next to the LMDS/MMDS systems a newer standardised FWA technology is emerging: the WiMax standard[30] (802.16 / 802.16-2004).

Next to these FWA systems there is also Wireless LAN, a technology mainly developed as a hotspot or indoor LAN technology[31]. The different WLAN systems are listed in the following table:

Table 2. Wireless LAN Throughput by IEEE Standard (source: Intel Labs) [9]

IEEE WLAN Standard	Over-the-Air (OTA) Estimates	Media Access Control Layer, Service Access Point (MAC SAP) Estimates
802.11b	11 Mbps	5 Mbps
802.11g	54 Mbps	25 Mbps (when .11b is not present)
802.11a	54 Mbps	25 Mbps
802.11n (not yet available)	200+ Mbps	100 Mbps

29 For example: WLAN IEEE 802.11b/g uses 20 MHz for a channel, 802.11a 25 MHz; LMDS equipment a changeable channel bandwidth of 1,75-3,5-7 or 14 MHz

30 Standardized by the IEEE 802.16

31 Wireless LAN has in reality a lower effective end user data rate because of protocol overhead (Ethernet/ATM) and the over the air encryption overhead (the older WLAN Wireless Equivalent Privacy (WEP) or the newer Wi-Fi Protected Access (WPA)). User fora state a data rate decrease of 20-50%, e.g. for 802.11b it is found that products often do not realize the official 11 Mbit/s, rather 4.5 Mbit/s and even lower with WEP encryption turned on.

In the following figure the maximum speeds (according to standard) are listed, sometimes with certain assumptions for channel bandwidth and effective data rate.

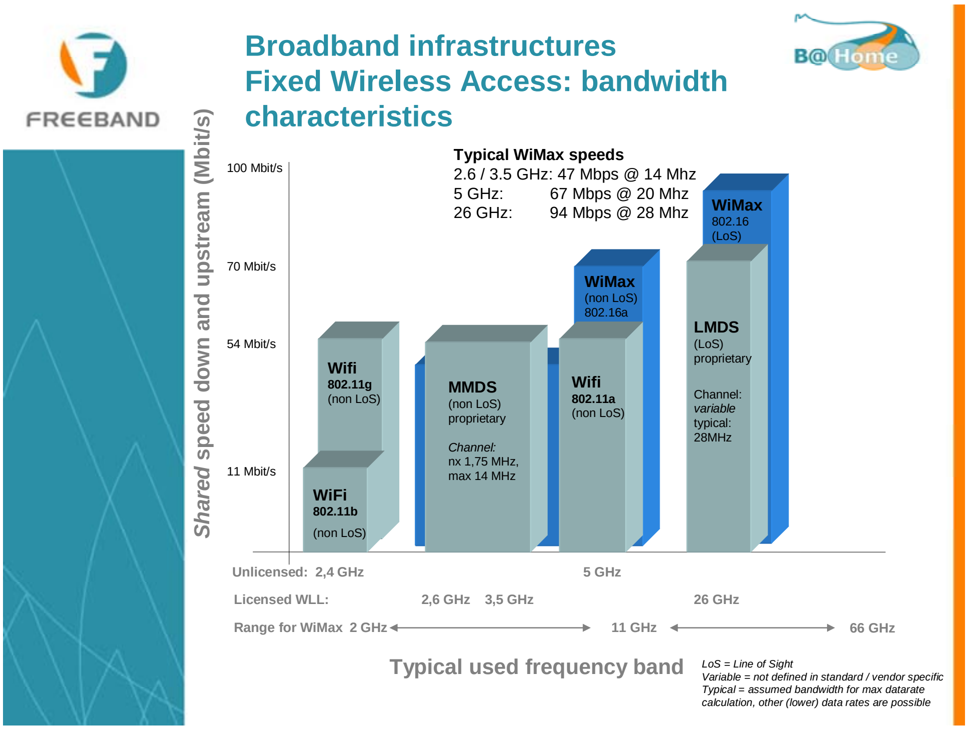

Figure 10. The capacity of different Fixed Wireless Access technologies compared.

When taking the maximum shared speeds from the above figure one can conclude that the data rates that can be offered to the customer will often be in *the mid-broadband speeds range (< 10 Mbit/s)*. *LMDS and WiMax 802.16a systems* operating in the *higher frequency bands* (higher than 10 GHz, e.g. the licensed 26 GHz frequency band) might have the possibility to offer up to 100 Mbit/s to the end-user, if not to many users share the capacity of one channel / base station. Also the data rate is dependent on the actual distance from base station to end-user, and when operating in unlicensed frequency bands it is dependent on the usage (interference) by other users and systems.

When looking at the capacity of the different FWA technologies it can be concluded that typical data rate delivered to an individual connected will be able to grow from the typical *mid-broadband speeds* nowadays (typical WLAN 802.11b/a user data rate around 10 Mbit/s) to the *lower range of super-broadband* speeds (up to 100 Mbit/s)[32].

There are no indications of FWA technologies, that can be used on a mass scale[33] in an access network that can deliver the higher end of super-broadband (500Mbit/s-1Gbit/s) or ultra-broadband speeds (1Gbit/s or higher).

Network QoS characteristics

Most of the FWA systems provide ways to prioritise traffic. For Wireless LAN systems this function was added more recently in a separate standard (802.11e), which newer equipment will implement. Other FWA systems have already incorporated certain QoS functions (LMDS, MMDS and WiMax). However when FWA systems operate in an unlicensed frequency band they might get interference from other users of this band and traffic that had a certain (higher) priority might still be dropped. This aspect is more unique to FWA systems, as wire line infrastructures suffer less from this problem[34].

Network security characteristics

As Fixed Wireless access uses radio to send the signals to the subscriber, this signal can be picked up by others in the vicinity of the base station. However most of the FWA systems support on the transport layer basic encryption. For Wireless LAN these are WLAN Wireless Equivalent Privacy (WEP) or the newer Wi-Fi Protected Access (WPA). LMDS and MMDS have often proprietary systems in place. One concern here is that often these encryption algorithms are being comprised by people finding ways to decrypt the traffic without the official key. FWA systems thus will not be able to deliver the same level of (physical) security protection as point-to-point wire line infrastructures (like DSL or FttH).

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32 However it should be mentioned that most channels speeds are shared among multiple users, therefore performance might differ, depending on how many users an service provider connects to one channel.

33 Free Space Optics is a FWA-technology that can realise super to ultra-broadband speeds, however due to larger and expensive equipment and LoS requirement it is not suitable as an consumer access network technology.

34 Although cable networks suffer from ingress-noise and DSL-networks from cross-talk impacting the overall network performance, the impact of interference in a unlicensed frequency band (from another legitimate user) for FWA systems will be much higher and might directly result in dropped package or the outage of the connection for a period of time.

Network availability characteristics

As stated in the Network QoS paragraph, the use of unlicensed frequency band might impact the QoS of and availability of the connection. This can be seen in the case of the use of WLAN, where at first only a few users had a WLAN base station in a apartment complex and now a few years after the introduction of this technology users are finding out they have to change channels because neighbours are using the same frequency and are interfering with their connection (until there no free channels are left to change to). For an operator wanting to use a FWA technology as an access network technology, over which triple play services need to be delivered (with for telephony high availability requirements) it might be to high a risk to use the unlicensed frequency bands (investing in an network where the performance might degrade over the years because of more usage by other operators and home users is not a very future proof investment).

Licensed frequency bands offer a solution to a part of this problem, in the Netherlands two ‘Wireless Local Loop’ frequency bands have been auctioned (2.6 and 3.5 GHz) with a third one expected (26 GHz). Also in other European countries these frequency bands have been auctioned and licensed to specific operators. However even in a licensed frequency band one is still susceptible to interference (e.g. unintentional interference, influence of extreme weather).

Also the use of the higher frequency bands (like 26 GHz) require that there is a Line of Sight (LoS) connection between base station and home transceiver. This means that trees, other (higher) buildings standing in the signal path between location of (potential) customer and base station might prevent this user actually being connected to the network. An operator rolling out FWA network with ‘LoS’ requirements should take extra care in planning most favourable signal paths to its customers, as trees might grow larger and new buildings might be build.

In the lower frequency band Non Line of Sight technologies can be used (like WLAN, MMDS and WiMax 802.16a), these frequency bands therefore are currently more suited for operators wanting to rollout a FWA network. This is shown in figure 11.

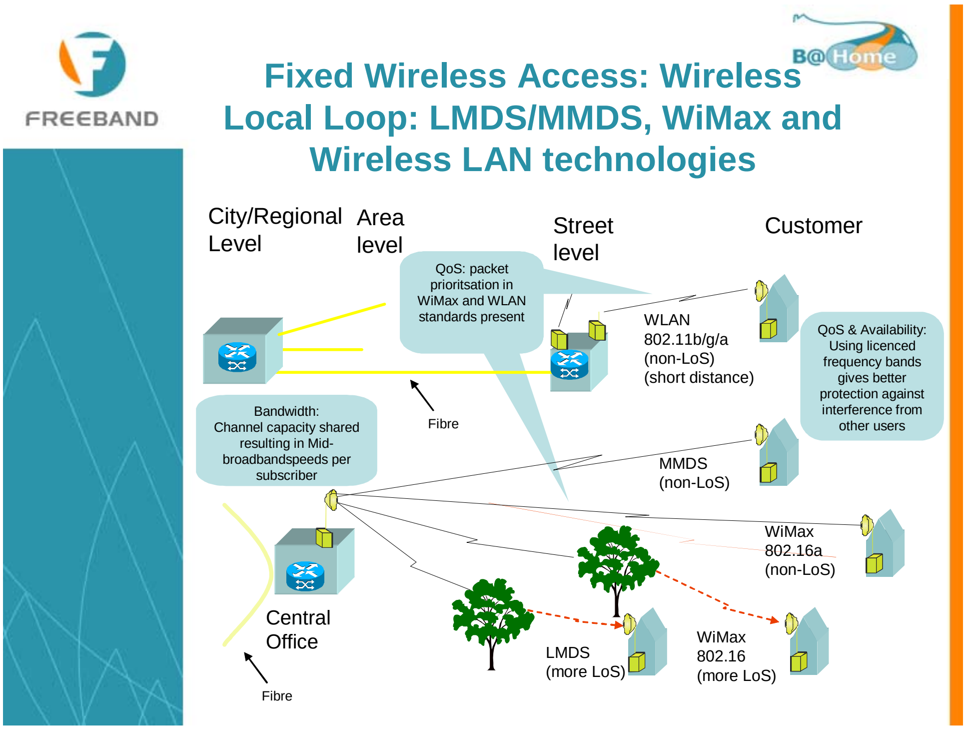

Figure 11. The Fixed Wireless Access technologies and their support for triple play requirements

3.4 Fibre to the Home

Bandwidth characteristics

The commercial use of fibre optics as a communication medium began in the 1970s for *long-haul* voice communication networks. The fibre offers virtually unlimited bandwidth capacity. The main developments regarding bandwidth are related to higher speeds on a single wavelength and new multiplexing techniques allowing multiple signals at different wavelengths to be transmitted on single fibre. In 1990 LAN data rates were 10 Mbit/s, in 1995 they were 100 Mbit/s and now we are moving towards 1Gbit/s and 10Gbit/s.

Using wavelength multiplexing techniques certain standards (like 100(0)Base-BX standards) can use one fibre for up- and downstream. With the popularity of fibre growing in both the LAN/WAN market and the long-distance (transatlantic) connections, the cost of the fibre and optical components have dropped to a price that also fibre as an *access* technology becomes possible. Companies, building co operations and sometime the users themselves supported by the local municipality in certain cities are already rolling out Fibre to the Home (FttH).

Fibre optics also has the ability to transfer data over longer distances than DSL and Cable-modem systems, thereby reducing the costs of the active components required to regenerate the data. The evolution of the fibre standards in relation to speed, fibre type and distance are shown in the following figure.

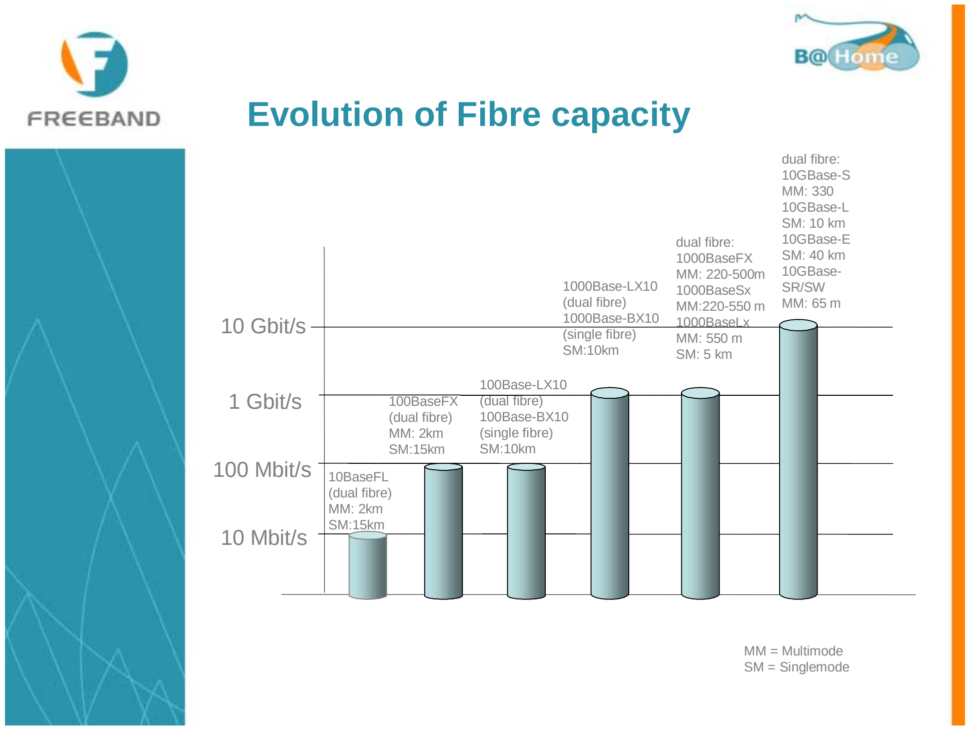

Figure 12. The evolution of fibre transmission standards.

From this figure it can be concluded that fibre as a transmission infrastructure can support from mid-broadband (up to 10 Mbit/s) to super-broadband speeds (up to 1Gbit/s), to even ultra-broadband speeds (1Gbit/s and higher).

Network transmission technologies used to realise data transport over fibre in an access network are Optical Ethernet (which are commonly used in the LAN/WAN market) and Passive Optical Network. As stated in chapter 2, FttH networks using Optical Ethernet systems applied in access networks (often local initiatives) often realise 100Mbit/s towards the end-user, however this can be upgraded to higher speeds in future if needed, by only replacing active equipment. PON networks can support nowadays up to 1 Gbit/s symmetrically, but are shared among several users. The sharing will result in a lower data rate per customer in comparison with Optical Ethernet, but will lead to less deployed fibre underground.

In general both Optical Ethernet and PON have enough bandwidth to support triple play services.

Network QoS characteristics

PON systems using ATM (APON, BPON) where one of the first systems to deliver both QoS and super-broadband speeds for an access network operator wanting to roll out triple play services over fibre. However also the Ethernet based Optical Ethernet products nowadays have several ways of support the needed QoS of services[35].

Network security characteristics

As a shared medium PON systems implement (like cable and FWA system) a basic level of encryption to protect the transmitted data from other people listening in (within the A/BPON standard this is standardized and is called 'churning'; other PON implementations use proprietary algorithms). FttH using Optical Ethernet technology is point to point, using a dedicated fibre(pair) per subscriber, and thus has some physical security on this level. However since the Ethernet traffic of all customers is aggregated in the switch it is possible to eavesdrop on traffic from other subscribers if the switch is not configured properly. A solution is using Virtual LAN tags to segregate traffic from individual or groups of users[36].

Network availability characteristics

The availability of the passive FttH network is comparable with other fixed wire line broadband networks, it could be considered possibly even a bit higher as it does not suffer from interference, crosstalk or ingress noise problems (as is the case with telephone and cable networks).

The issues regarding powering and lifeline functionality exist in the same way as they exist with DSL and cable networks.

[35] Most Ethernet switches support 802.1p priority tagging and implement this with queues inside the switch.
[36] Most Optical Ethernet switches support the 802.1Q VLAN standard for traffic seperation

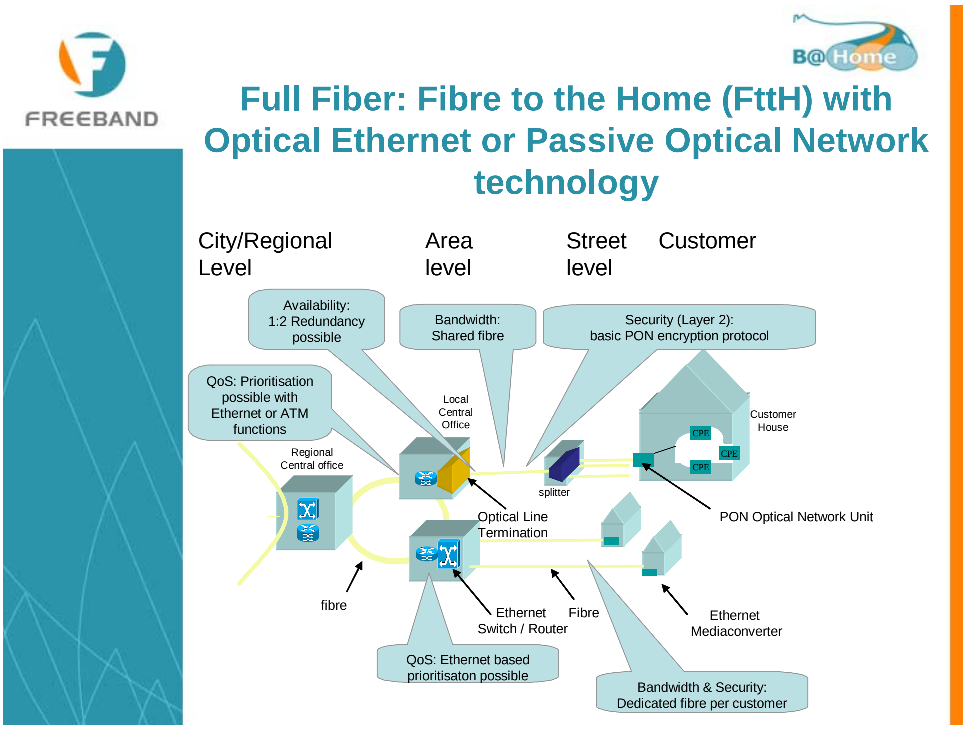

Figure 13. The FttH technologies and their support for triple play requirements

3.5 Summary of characteristics of broadband networks

Bandwidth

The access technologies can be categorized according to the bandwidth classes as defined in section 2.1, namely, mid-broadband (between 128 kbit/s and 10 Mbit/s), super-broadband (more than 10 Mbit/s symmetrical) and ultra-broadband (more than 1 Gbit/s).

Mid-Broadband network speed

Broadband internet penetration in the Netherlands is mainly driven by ADSL (telephone network) and cable-internet (the Hybrid Fibre Coax network, HFC). The speeds that are currently offered by these networks vary from 128 kbit/s (low entry 'light' package) to maximum of 4-10 Mbit/s[37] downstream. In rural areas some 'Fixed Wireless Access' operators are active by using WLAN 802.11a/b/g standards or a proprietary transmission technology offering shared access at speeds between 10-54 Mbit/s[38] often resulting in effective end user speeds of around 1 Mbit/s or lower. In most cases these services offer a lower upstream speed than downstream speed (asymmetrical connection).

Generally, the *current ADSL, Cable Internet and Fixed Wireless* Internet networks are capable to deliver 'asymmetrical mid-broadband' speeds.

From Mid-Broadband to Super-Broadband network speeds

The current mid-broadband networks have a potential of being upgraded to speeds higher than 10 Mbit/s. The existing telephone network can shift from ADSL to the higher speed ADSL2(+) and VDSL-technologies[39] and cable networks can be upgraded by using higher speed EuroDocsis and/or CableEthernet techniques[40]. The growth of both the telephone network and cable network capacity is compared in the following figure using the data from figures 6 and 8.

[37] 8 Mbit/s downstream is maximum for ADSL, maximum cable speeds *currently* offered are around 4-10 Mbit/s downstream depending on provider (based on information offered on websites of Wannadoo/Casema, @Home, Chello jan 2005)

[38] IntroWeb uses an proprietary product in the 2.4 GHz ISM band (same frequency band as the WLAN 802.11b/g standard) with speeds of 512kbit/s and 1 Mbit/s

[39] Copper : VDSL can deliver theoretical maximum of 28 Mbit/s, Belgacom will rollout VDSL at speeds of 15 / 5 Mbit/s (down/up)

[40] Cable: Upgraded cablenetworks can deliver speeds ranging from 10 Mbit/s to 16 Mbit/s (based on speeds achieved during consumer-trials of Kabelfoon/CaiWestland, @Home/Essent and Wannadoo/Casema).

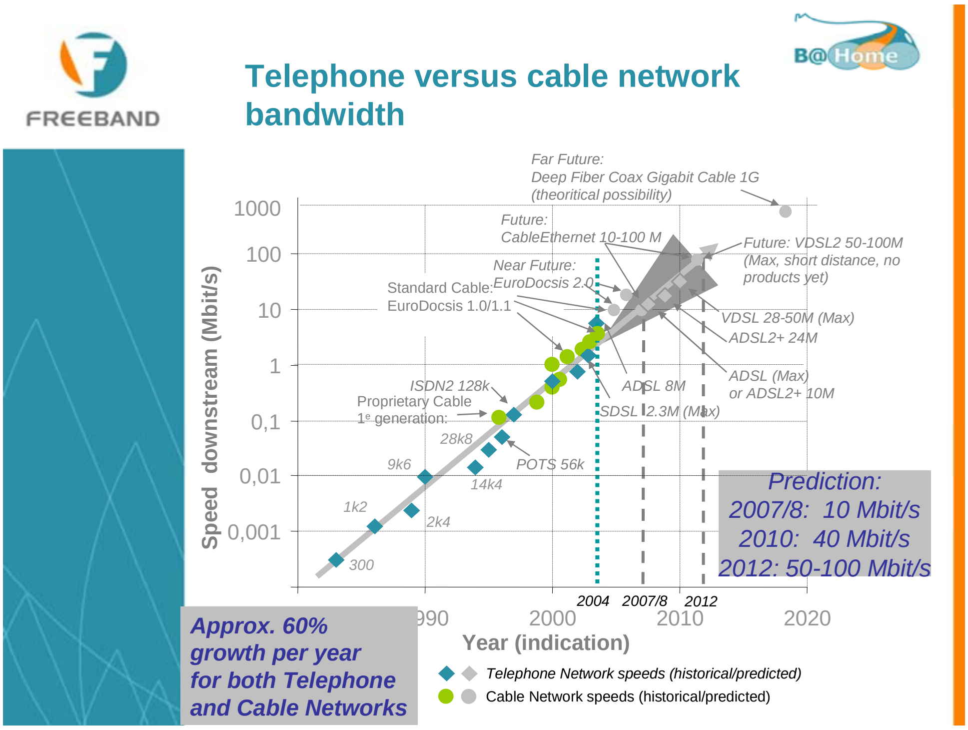

Figure 14. The capacity growth of the cable network and telephone network compared.

From figure 14. one can determine a historical annual capacity growth of approximately 60% per annum. Assuming the same 'automonous' growth in the future, one can predict when it is most likely that a certain speed will be introduced. Furthermore, from this figure it can be concluded that both the cable networks and the telephone network in the Netherlands have a similar capacity growth rate.

Using the growth rate of 60% per annum and extrapolating this towards the near future one can predict that it is likely that in the period 2007-2008 network speeds of 10 Mbit/s will be available to *most of* the consumers by means of broadband technologies over both the cable and telephony network ('mass-market availability').

Cable networks will mostly use EuroDocsis be used to support these speeds will be EuroDocsis. It will be the most used technology up to 2010 to support speeds up to 40 Mbit/s. After that the Cable Ethernet technology will have an opportunity to realize speeds between from 10 towards 100 Mbit/s. Also the EuroDocsis 3.0 standard currently in development will be able to realise 100Mbit/s or higher by using the bandwidth of several channels (compared to EuroDocsis 2.0 who is limited to single 8 MHz channels)[41]. It

[41] Eurodocsis 3.0 cablemodems can be configured to use more than the regular 8 MHz bandwidth (eg 16 MHz), so it can support higher bitrates, this way multiples of 38 / 52 Mbit/s will be possible

should be noted that the introduction of Cable Ethernet implies upgrades[42] to the rest of the cable network as the Cable Ethernet technology will have a limited reach.

Regarding the telephone network it can be predicted that in 2010 the access network will be using ADSL2+ and/or VDSL technology to reach speeds up to 50 Mbit/s. Here it is assumed that the telephone network is being upgraded with fibre in the access network.

When looking towards 2012 it is (at this moment in time) unclear if the telephony network will be able to deliver speeds from 50 Mbit/s up to 100 Mbit/s using the VDSL2 standard to *all* (or substantial number) potential subscribers. This is due to the fact that it is unclear what the effects will be of interference by other DSL-users (crosstalk) on the performance of VDSL2 to reach these higher speeds.

In the year of 2010 the typical speed with mass market availability will be around 40 Mbit/s for both cable and for telephony networks, assuming some upgrades to both networks. Assuming the growth rate will continue to stay the same, in 2012 these networks should be able to achieve 100 Mbit/s. For the telephone network, however, it is unclear if this speed will become available to *all* end-users.

Fixed Wireless Access (FWA) network operators will be able to evolve towards more broadband speeds by using new technologies (WiMax) and migrating from unlicensed to licensed frequency bands, where there will be less interference from other users[43]. Fibre to the Home is already rolled out in some cities in the Netherlands. Currently FttH operators deliver Internet access at speeds more in the mid-broadband than super-broadband range, however these networks have the capability to support speeds of 10 to 100Mbit/s to each end-users without any upgrading of the network[44].

A *combination* of newer transmission technologies and physical upgrading of the network (DSL, Cable) or using newer (licensed) frequency bands (FWA) will enable the telephony, cable and FWA networks to deliver 'middle to super broadband (lower end)' speeds (10-100 Mbit/s) in the near future. Also the new rollout of FttH networks in certain cities will of course be able to support these speeds.

[42] With CableEthernet headend equipment will be placed closer towards the end-user in the street cabinets, the connection to the central network of this street cabinet will be realised with either more fibres or using the coax network with newer higher bandwidth modems to transmit the aggregated data of the Ethernet-connection signals over the cable in higher frequency bands towards the head end.

[43] Fixed Wireless Access: IntroWeb recently started using the licensed 2.6 GHz frequency band in combination with the WiMax technology, offering end user speeds between 1-5.5 Mbit/s.

[44] Fibre : Where FttH is rolled out in the Netherlands, it is done usually with an infrastructure supporting 100 Mbit/s towards the customer (line-speed). Typical data rates for the Internet service over FttH currently range from 2Mbit/s to 10 Mbit/s (based on offering of Concepts-ICT FttH (Amsterdam and Enschede) and Daxis (Appingedam)). The rest of the capacity can be used for delivering IP-based 'Broadcast' and 'On demand' Video services and other local services, or as spare capacity to be used for new upgraded Internet access service packages later in the coming years.

Ultra broadband speed

In the distant future we can already envision access networks being capable delivering speeds of 1 Gbit/s and higher. This can be supported by Fibre to the Home networks that often already have chosen a fibre type that will be able to support 1 Gbit/s and higher if needed[45]. Also cable networks have the potential of delivering 1 Gbit/s. This can be achieved by using the total frequency spectrum of a coax cable (including the portion that is now used for TV-distribution) for transmission. However this does mean only a short distance can be covered by coax and it should be used in a point-to-point mode[46]. The rest of the (feeding) coax-network should consist of fibre (a very 'deep' Hybrid *Fibre* Coax network). Although it is currently unknown if this will be implemented, this may be considered as an option for the far-future. Regarding Fixed Wireless Access techniques, when using Free Space Optics speeds of 100Mbit/s to 1 Gbit/s can already be achieved, however this technique is not suitable as an access network technology for use in a consumer market (due to rather large receive/sent equipment, more difficult installation and cost of equipment). However it will have some use in connecting businesses.

When ultra-broadband speeds need to be realised, single mode FttH infrastructure will be the most eligible access technology option to realise this. It can be envisioned though assuming new technological advances, and network upgrades cable will have some capability to reach towards ultra-broadband speeds in the *far*-future.

In general, as newer access technologies are used to enable more broadband speeds more fibre is needed in the access network 'feeding' the last mile of the network, resulting in a Hybrid Fibre access network. In the *far*-future this results in full Fibre to the Home, evolved from the current copper/coax networks or directly installed as a new (greenfield) network. This is shown in the following figure.

[45] Fibre: 1 Gbit/s speeds over fibre can be achieved when 'single mode' fibre is chosen.
[46] Cable: assuming 50 'free' channels (previously used for analogue and digital TV-broadcast) each capable of carrying 38 Mbit/s the 'total' speed of a coax cable (when using the whole bandwidth for data) can be around 2 Gbit/s.

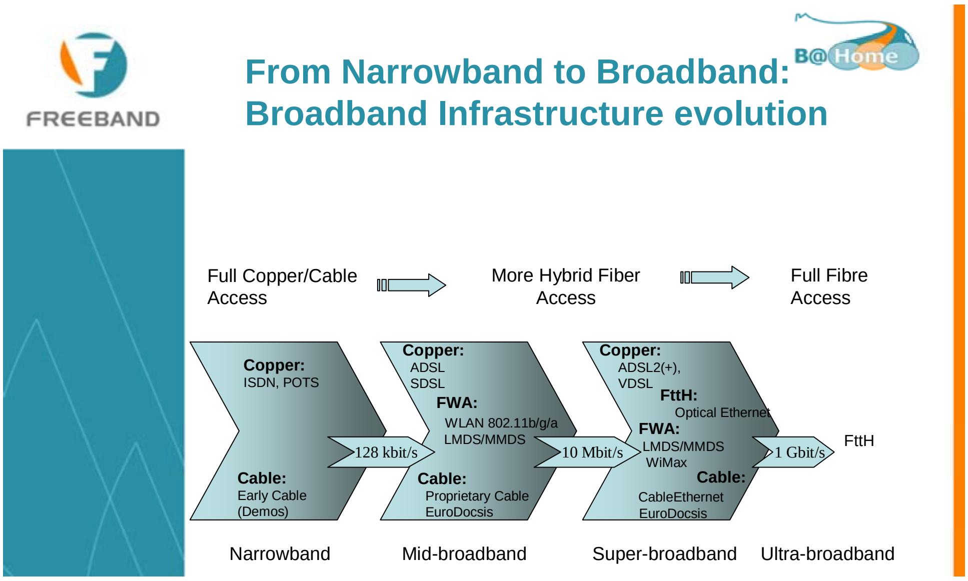

Figure 15. Different access technologies evolving from narrow-, to mid-, super- and ultra-broadband

In the following two tables the characteristics as mentioned in this chapter are summarised.

Table 3. Summary of broadband network characteristics (telephone and cable network)

Broadband Networks and their transport technologies	**Bandwidth characteristics:** **Speed to *enduser* (subscriber)**	**Network QoS characteristics:**	**Network Security characteristics:**	**Network Availability characteristics:**
Telephony network ADSL, SDSL	**Mid-broadband speeds** Asymmetric (ADSL) Symmetric (SDSL) Dedicated connection per subscriber	**Present** Support for basic Layer 2 (ATM based) QoS services possible	**High** by dedicated physical connection per subscriber	**Medium to high Availability** The telephone network has high availability.
ADSL2, ADSL2+, VDSL	**Mid- to Super-broadband** speeds possible Symmetric and Asymmetric modes possible Dedicated connection per subscriber	Newer DSLAMS integrate Layer 2 and Layer 3 QoS functions. More advanced features possible with rollout newer DSL technologies	No layer 2 encryption of DSL traffic necessary End to End encryption done in Layer 3 and higher (VPN tunnels, applications)	However in case of power failure in current DSL rollout no end-user backup facilities in place to support e.g. lifeline functionality for telephony service
Cable network				
EuroDocsis technology	**Mid- to Super-broadband** speeds to subscriber possible Shared cable modem channel capacity, but with correct network dimensioning (segmentation) good performance attainable	**Present** Support for different traffic classes and packet prioritisation (E.D. 1.1 and higher)	**Medium to High** as a shared medium Layer 2 encryption is possible (Base Line Privacy + specification) if used high network security is possible	**Medium to high Availability** The cable network has high availability. No lifeline functionality for telephony service in place in current rollouts

Table 4. Summary of broadband network characteristics (Fixed Wireless Access and FttH)

Fixed Wireless Access				
WLAN 802.11b/g/a	**Mid-broadband** WLAN 802.11b Mid-broadband WLAN 802.11g/a low end of Super-Broadband Shared channel capacity, when WLAN is used as access network technology and channel capacity is shared among multiple users the result will be more *Mid-broadband* speeds to subscriber	**Low to medium** With additional 802.11e standard QoS features present, but 802.11 equipment work in unlicensed frequency band, no assurance of real QoS for end-user services	**Low to Medium** As a radio medium traffic can be received by other users in neighbourhood of base station WEP and WPA Layer 2 encryption possible (WEP encryption is not to strong)	**Low to Medium** WLAN equipment uses the license free frequency band. No guarantee that other users will start to interfere WLAN technology in 2.4 and 5 GHz frequency band can be Non-Line of Sight providing better coverage/availability then LoS technologies
MMDS LMDS	**Mid-broadband (possible to lower end Super-broadband)** Shared channel capacity: LMDS might attain slightly higher data rates than MMDS by using higher frequency band	**Medium** usually some proprietary mechanisms present. L/MMDS uses licensed frequency band	**Medium** usually some proprietary mechanisms present	**Medium** L/MMDS uses licensed frequency band and will have less interference from other users MMDS is Non-LoS LMDS is LoS
WiMax 802.16a 802.16	**Mid-broadband (possible to lower end Super-broadband)** When using frequency band < 11 GHz Shared channel capacity **Mid-to Super-broadband** when using frequency band > 11 GHz Shared channel capacity	**Medium to High** QoS functionalities present in 802.16 standard WiMax can use both licensed and unlicensed frequency bands, this may impact QoS in practice	**Medium** Encryption mechanism present in 802.16 standard	**Low to Medium** WiMax can use both licensed and unlicensed frequency bands, this may impact availability
FttH				
A/B/EPON Optical Ethernet	**Mid-broadband to Super-broadband** Shared medium, but channel rate high (622-1Gbit/s) **Mid-broadband to Super and Ultra-broadband** Dedicated connection to each subscriber	**High** For APONs QoS functionalities present using ATM functions For EPON and Optical Ethernet, Ethernet type QoS functions present	**Medium to High** For PON networks some basic layer encryption present Optical Ethernet has dedicated connection per subscriber, no Layer 2 security needed	**Medium to high Availability** A FttH network has high availability. However in case of power failure in current FttH rollout no often no lifeline functionality for telephony service

4 Conclusions

Bandwidth requirements versus network capacity

When comparing the predicted increase in triple play bandwidth requirements with the expected network capacity growth one can conclude that all current broadband networks (the telephone network, cable networks and fixed wireless networks) can adequately support triple play services with *'normal' quality*.

Among these 'normal quality' services are services like full screen video telephony, VHS/TV quality live or on demand video, CD quality audio, teleworking with 1-10 Mbit/s speed access and file sharing enabling the download from individual songs to complete audio CD's within 7 minutes.

When services evolve to *'higher' quality* and are *used concurrently* by family members in one household, networks supporting *super-broadband speeds* (>10 Mbit/s) will be needed to support the bandwidth requirements of these services and users. These 'higher quality' services are High Definition quality TV and on demand video services (both with optionally also higher quality / multi-channel audio), teleworking with a full speed access to the corporate LAN and file sharing (enabling the download of the original content of a complete DVD) within 7 minutes. Also for gaming super-broadband speeds can be used in order to realise an almost 'instant' game download and participation. The full screen, HD-video telephony services can of course also be offered over super-broadband networks.

Both cable and telephone networks will be able to support *'the lower end'* of these *super-broadband speeds* (10-100 Mbit/s) with some network upgrades, but for the telephone network it is unclear if it will be able to support this to *all* users. Fixed Wireless Access technologies like WiMax and Wireless Local Loop (LMDS/MMDS) might also be able to realise the same speeds when not *too many* end-users *share* the wireless channel capacity. This is summarized in the following figure.

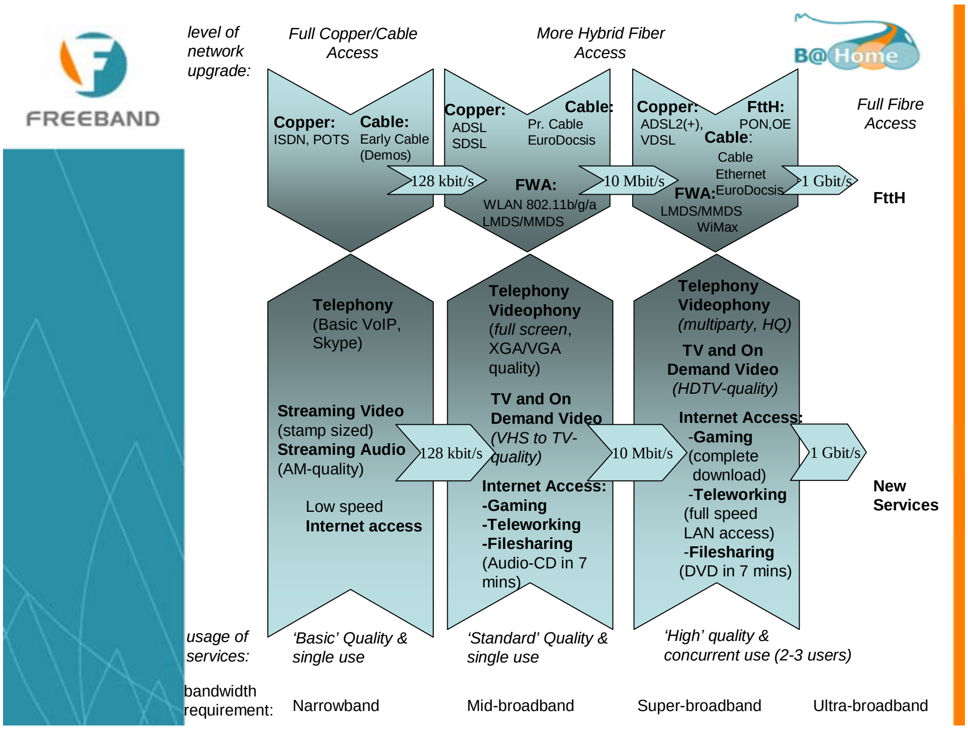

Figure 16. The change in service bandwidth requirements and network capacity compared

With services evolving to 'high' quality and more concurrent use, Fibre to the Home will start to become the more future proof network with speeds from 10 to 100 Mbit/s guaranteed for *all* subscribers and ultimately being able to transport 1Gbit/s *if* new services require this. However as can be seen from figure 16, currently *all* 'normal' and 'high' quality services can be transported over either current or upgraded broadband networks. It will be more futuristic 'new' services like 3D Television or 3D videoconferencing that might be possible drivers behind the migration from mid- to super-broadband hybrid fibre coax / copper networks to ultra-broadband full fibre to the home networks.

Network QoS, Security and Availability requirements versus network-characteristics

As IP-based services delivered over broadband networks start to become real substitutes for their conventional counterparts (like VoIP-based telephony and IP based TV/on demand video versus analogue telephony or regular TV) the requirements will also increase from low to high quality of service and availability requirements. In the beginning first generation broadband equipment (most apparent with 1st generation cable modem systems) did not have (enough) quality of service mechanisms. Currently all broadband networks have mechanisms in place which can be used to ensure the priority of the traffic of for example a telephone call over regular internet traffic (quality of service). This means that although in practise these mechanisms are not always used yet, in the near future when the higher quality requirements start to become more apparent, most broadband networks will be able to offer this. This is shown in the following figure.

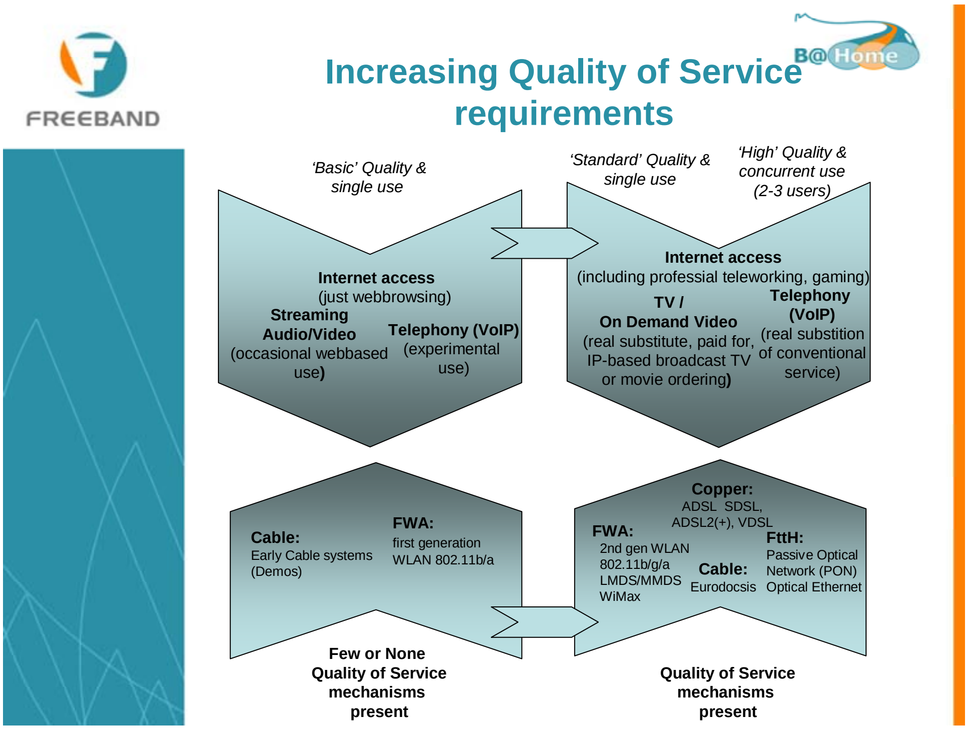

Figure 17. The quality of service requirements and network characteristics compared

Regarding the high availability requirement, it can be seen that most wireless networks might suffer (short) outages from direct interference in the frequency band they are using. Especially fixed wireless access networks that use unlicensed frequency bands can suffer from other (legitimate) users in the same frequency-band. In case of both wire line and wireless networks some attention might be needed in ensuring power backup for the connected active equipment (both in-house and at the central office location).

Most security requirements of services are handled by the applications involved. Point to point wire line networks (like the telephone network and Optical Ethernet based fibre to the home) intrinsically have an advantage in realising network level security when compared to shared media networks (the cable network and PON-based fibre to the home), where potentially network users can monitor the downstream traffic of their neighbours. Wireless networks have a lower ability to support network based security because also users *outside* the network can monitor traffic. For this reason shared media and wireless networks often encrypt the data that is transported to alleviate this problem; however is it not uncommon that these encryption systems are compromised.

Timeline

The prediction of when the shift from 'basic' quality to 'high' quality services will be made is difficult to make, especially since this is both dependent on *when* broadband network are able to realise the capacity needed to transport these services ('technology push') as when the user actually will want these services ('market pull'). Next to these factors the market strategy of both the content owners (e.g. movie studios) and service and network providers will determine *when* they will 'allow' the shift to higher quality services (with possible different business models), contradictory interests might delay the introduction.

When looking purely at the growth factor of network capacity one can get an indication when 'from a network point of view' a 'service shift' *might* happen ('technology push'). Taking the growth factor of both cable and telephone networks around 60%~ (as described in chapter 3) one can predict that 'lower end' super-broadband speeds (10-100 Mbit/s) will become available in the 2007– 2012 time period for most consumers ('mass market availability). In this time frame the shift to more 'high' quality services (like HDTV and professional teleworking) can be made by service providers, with however an uncertainty on the adoption rate of these services by the consumer.

From 2012 onwards with the availability of 100 Mbit/s (on upgraded telephone and cable networks and more fibre networks) 'new' services will have to opportunity to materialize (services not yet thought of at this moment in time).

Conclusion

In the coming years both cable and telephone networks will be able to support the shift from *'basic'* quality to '*higher' quality triple play services* by *upgrading* their networks towards *more hybrid fibre* infrastructures in combination with other techniques. Fixed wireless networks can have similar capacity capabilities as long as not too many users share this. Some attention might be needed by fixed wireless operators regarding the availability (especially when using unlicensed frequency bands). If 'lifeline' functionality is needed (for the telephony service) all broadband networks will need to take extra measures regarding power backup.

As network speeds higher than 100Mbit/s become more mainstream from 2012 onwards, the Fiber to the Home (FttH) network technology will gain popularity as the more future proof broadband technology able to deliver high speed access to *all* potential users in the network. Next to newly build FttH networks, cable en telephone network operators will be able to realise this by taking the upgrade of their networks on step further towards a full fiber to the home network.

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Credits:

The author would like to thank to following people for their input and review commentary to this paper:
Dr. Ir. S.S. Op de Beek, Dr. Ir J.M.M. de Nijs , Ir. J. Burgmeijer and Dr. B.M. van den Heuvel