DVB-H in Denmark
Technical and Economic aspects

Master's Thesis

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ABSTRACT

The demand for multimedia services including mobile TV to mobile handset is increasing rapidly. Mobile TV is nowadays delivered on *point-to-point* 3G cellular networks. Being unicast in nature, these networks remain an inefficient method for simultaneous delivery of TV services to a mass audience. An alternative to the 3G cellular network is the *point-to-multipoint* DVB-H broadcast network, which has been designed for the delivery of mobile TV on handheld terminals. This is considered to be ideal for content delivery to a large number of users and to cater for an increased demand for mobile TV services.

The purpose of this project is to investigate the possibility of deploying a DVB-H network in Denmark. The investigation is carried out by means of describing the general features of a DVB-H network. This includes technical constraints and network planning issues such as network topology, coverage, radio frequency and radio transmit power as well as a cost estimate of deploying a DVB-H network in Denmark.

In particular, this thesis addresses the theory behind DVB-H. Also, in this paper an analysis of the economy of the 3G cellular and DVB-H network is conducted to understand the benefit of DVB-H compared to the 3G network. Results show that mobile TV over 3G networks will neither be profitable nor sustainable as it fails to serve mass mobile consumers. Although 3G cellular networks can be upgraded to MBMS or HSDPA to deliver higher data rates and support a significant number of subscribers, it has failed to support millions of subscribers during busy hours. Despite the difference between the broadcast and cellular networks, research has shown that these networks can be combined for successful delivery of mobile TV service. In order to show the benefit of the combined networks, a network convergence business model is presented. An evaluation of the different existing mobile TV broadcast technologies is also discussed to understand the benefit of DVB-H compared to the existing technologies. The main concern for the broadcasters and mobile operators alike with regards to DVB-H is the cost associated with the implementation of DVB-H network infrastructure. Two case studies are presented to estimate and evaluate the DVB-H deployment cost in Denmark.

Furthermore, an analysis of the evolving market opportunity for mobile TV is presented and finally, recommendations for adapting DVB-H technology will be discussed, in the hope that this technology will be deployed in Denmark in the near future.

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GLOSSARY

2G	second-generation
3G	third-generation
ARPU	Average Revenue Per User
AVC	Advanced Video Coding
ALC	Asynchronous Layered Coding
BER	Bit error ratio
BSD	Broadcast Service Danmark (www.bsd.dk)
CCI	Co-Channel Interference
COFDM	Coded Orthogonal Frequency-Division Multiplexing
CPAEX	Capital expenditures
DAB	Digital Audio Broadcasting
DQPSK	Quadrature phase-shift keying
DRM	Digital rights management
DVB-H	Digital Video Broadcasting - Handheld
DVB-T	Digital Video Broadcasting - Terrestrial
EIRP	Equivalent isotropically radiated power
EPG	Electronic Program(me) Guide
ERP	Effective radiated power
ESG	Electronic Service Guide
FEC	Forward error correction
FLUTE	File Delivery over Unidirectional Transport
GSM	Global System for Mobile communications
HDTV	High-definition television
HiWire	
HSDPA	High-Speed Downlink Packet Access
HTML	Hypertext Markup Language
IP	Internet Protocol
IPDC	Internet Protocol Datacasting
ISDB-T	Integrated Services Digital Broadcasting Terrestrial
MBMS	Multimedia Broadcast Multicast Service
FLO	Forward Link Only
MMS	Multimedia Messaging Service
MP3	Audio Layer 3
MPE	Multi-Protocol Encapsulation
MPE-FEC	Multi-Protocol Encapsulation Forward Error Correction
MPEG	Moving Picture Experts Group
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational expenditure
PDA	Personal digital assistant
PKI	Public key infrastructure

QAM	Quadrature amplitude modulation
QPSK	Quadrature Phase-shift keying
S-DMB	Satellite Digital Multimedia Broadcasting
SDTV	Standard-definition television
SFN	Single-frequency network
SMS	Short Message Service
TDC	Tele Denmark Communications (www.tdc.dk)
T-DMB	Terrestrial Digital Multimedia Broadcasting
TPS	Transmission Parameter Signaling
TV	Television
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunications System Very high frequency
VHF	Very high frequency
WCDMA	Wideband Code Division Multiple Access
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
XML	Extensible Markup Language

1. GENERAL INTRODUCTION

This introductory section contains motivation for research, problem statement, objectives and structure of the thesis.

1.1 MOTIVATION

Today, mobile phones are taken for granted. However, that has not always been the case. The use of mobile phones has gone through profound changes since its introduction onto the market. The technological development has made it possible to offer many different services to the modern mobile consumer. New services include WAP, file transfer, multimedia messaging, email applications, mobile commerce, camera, games and larger memory, up to several gigabytes in size, making a variety of new functionalities possible.

Years ago, no one could imagine that the evolution of technology would bring multimedia services to the mobile environment. Many technologies are now available and new technologies are continuously arriving. The technology leap from 2G to 3G has been a multimedia breakthrough providing better multimedia services and higher transfer speed.

The transition from analogue to digital broadcasting has been a big advantage in terms of bandwidth and new user applications. At the time, DVB-T technology made it possible to transmit digital TV signals to our TV sets at home. A new technology, the DVB-H standard broadcast, has recently been introduced on the mobile market. DVB-H technology brings TV broadcast services to the mobile handset and many believe that DVB-H will be the dominant technology for mobile TV.

The first experiment with DVB-H has been realized in Finland with 500 users in Helsinki, and many tests are taking place in Denmark and in different countries around the globe. In parallel with the DVB-H tests, international analysts predicted that the market will explode in 2010 with 250 million subscribers, and that it will generate nearly 27 billion dollars [1].

TV and the consumer’s use of television communication have undergone significant changes. Today, television is a central part of many people’s everyday lives and contains a rich and varying range of entertainment, education and information programs. The number of mobile telephone owners in the world has increased explosively over the last years. Surveys are indicating further development on the mobile telephone market, and the results show that users are likely to watch mobile TV for an average of 20 minutes per day while they are on the train, metro or bus [2]. This prediction reveals that the global market for mobile TV services is likely to grow in the future.

Evidently, there is no doubt that mobile television is a service that interests many people not only here in Denmark but all over the world.

1.2 PROBLEM STATEMENT

Since mobile television is a new service on the Danish market, there is still uncertainty about many fundamental factors such as which technology will be used for a successful mobile TV service. The broadcasters' and mobile operators' major concern is whether mobile television in the future will be sent through the existing mobile networks or whether new networks will need to be built. Currently, they are seeking advice on which of the existing technologies they should concentrate their resources on.

Actually, there are two possibilities when offering mobile TV on mobile handsets. The first consists of exploiting already existing networks such as UMTS or 3G. These standards being unicast in nature have a problem of scalability and are not suitable for serving millions of users. The second possibility relies on broadcast networks based on standards such as DVB-H. These networks are capable of sending the same content simultaneously to a large number of mobile receivers.

Apparently, no wide acceptance for deploying DVB-H has yet been adopted in Denmark. There is still uncertainty about taking initiative and many players on the market may be unwilling to take a large financial risk of investment. One of the major concerns is the deployment cost of the DVB-H network infrastructure. This is probably because it has a great impact on the price of TV services, which may be unaffordable for the mobile consumers. There are several players on the market, dictating the requirements for the deployment of DVB-H, which is one of the reasons it is difficult to introduce such technology. Other reasons include various practical concerns such as frequency spectrum allocation, a viable business model, capital requirements of network infrastructure, service quality and viewing experience in a challenging mobile environment.

This thesis seeks to answer the following questions:

1- Is it possible to use existing cellular mobile technologies such as 3G networks for mobile TV services?
2- Is it possible to use existing broadcast technologies such as DVB-T for mobile TV services? If so, what are the problems that might be encountered such as in indoor and outdoor coverage, mobility, capacity, etc.
3- Why choose DVB-H?
4- What are the challenges in deploying DVB-H?
5- How much does it cost to build a DVB-H network in Denmark?

To answer these questions, this thesis will initially describe the technologies involved and the fundamental aspects of DVB-H. This shall outline and describe the challenges of providing a successful deployment of DVB-H.

On that basis, this thesis will analyze the DVB-H technology and compare it to the existing technologies, such as 3G and DVB-T. The expected conclusion will be an evaluation of DVB-H based on the requirements needed to introduce it successfully for the deployment of mobile TV in Denmark.

1.3 THESIS OBJECTIVE

The aim of this thesis is to investigate the feasibility of deploying a DVB-H network in Denmark. The investigation is carried out by means of describing the general features of a DVB-H network. This includes technical constraints and network planning issues such as network topology, coverage, radio frequency and radio transmit power. Finally, it includes addressing economic issues as well as a cost estimate of deploying a DVB-H network in Denmark.

To achieve this aim, a number of tasks need to be addressed including:

1. Study the technical aspects of DVB-H and discuss the network planning issues to implement this technology.
2. Study and compare currently existing mobile TV technologies with DVB-H.
3. Study the DVB-H network infrastructure, hardware requirements and the different components of the DVB-H networks.
4. Estimate the cost of a DVB-H network investment, with respect to the possibilities of deploying a mobile TV in Denmark.

The second objective of this thesis is to provide background information as well describing the major concepts and issues concerning the DVB-H technology.

1.4 STRUCTURE OF THE THESIS

After the introduction here in section 1, in section 2 some basic concepts of digital mobile TV will be discussed. This section provides an introduction to the mobile TV and as well as discussing the Danish supply of mobile TV. This section also describes the different pilots taking place in Denmark and all over the world. The drivers of mobile TV technology are also described.

In Section-3 an overview of mobile TV technologies that nowadays exist on the market are presented. This section includes a presentation of broadcast and unicast technologies and a discussion of a possible substitute for mobile TV using podcasting technology. Other potential carriers for mobile TV such as wireless technologies are also discussed. Mobile TV services on cellular networks and digital terrestrial transmission technologies are studied to understand definitions and the characterizing properties with regards to DVB-H.

The focus in section-4 will be towards Digital Video broadcasting on Handheld (DVB-H). This section discusses the technical aspects of DVB-H to understand how this technology works. The extra features that have been added to its predecessor DVB-T technology are also discussed into details. These include:

- Time slicing for power saving and seamless frequency handover
- MPE-FEC for additional data correction and Doppler performance in a mobile environment
- DVB-H signalling to enhance and speed up service discovery
- 4K mode for trading off mobility and SFN cell size as well as for allowing flexible network design and network performance

In-depth interleaving for 2K and 4K modes, IP-datacast, DVB-H protocol stack and security are also discussed.

Section-5 focuses on describing the technical usage scenarios of DVB-H. This section discusses the different possible network scenarios needed for successful mobile TV. The advantages and drawbacks of each of these network scenarios are also discussed.

Section-6 presents the technical challenges and the regulatory aspects for implementing DVB-H network.

Section-7 covers the practical part of the thesis. In this section the economics of unicast and broadcast technologies are presented. Economic analysis based on numerical results will be performed to understand the advantages of the broadcast technology over the unicast technology. Also in this section a business model that shows the financial benefits and the relationships between the different players in the value chain is described. The cost estimation of DVB-H network implementation based on a number of underlying assumptions is then calculated and evaluated based on two case studies. The future market for mobile TV and the evaluation of the results will also be provided in this section. Finally, Section-8 concludes the findings of the thesis with a summary of the work.

1.5 STUDY LIMITATIONS

There are some limitations that need to be acknowledged in this thesis. The first limitation concerns the lack of information about the prices of different components needed in the implementation of DVB-H network. This is due to the fact that the industry does not offer the prices of the DVB-H components. Therefore the calculations and evaluation of DVB-H network investment conducted in the case studies are mainly based on many underlying assumptions and data gathered from different sources and published papers available on the internet.

The second limitation is the lack of information, due to company confidentiality policies, about the resources of existing companies, such as the number of 3G sites implemented across Denmark and the number of subscribers. Therefore the reader of this thesis should be aware that the results obtained are only approximations. The results of the network investment should not be regarded as an exact financial forecast. These limitations might affect the study results and could significantly alter the conclusions of this study.

2. ABOUT DIGITAL MOBILE TV

To get a comprehensive view of the current status in terms of trials and development of mobile TV, in this section an introduction of mobile TV is presented along with details about the Danish supply of Mobile TV. This is followed by describing the drivers for mobile TV. Finally the mobile TV pilots taking place in different parts of the world are presented.

2.1 WHAT IS MOBILE TV

Mobile TV is the transmission of TV programs to media-enabled wireless devices such as mobile phones, PDAs or similar. More importantly, mobile TV is a technology that has been specifically designed to meet the requirements of the constrained environment of these devices, such as limited battery power and small screen size.

TV programs can be transmitted to mobile users in two modes: *broadcast* or *unicast*. In a *broadcast* mode the same content is made available to a large number of mobile users on their handsets simultaneously, whereas in *unicast* mode the content is transmitted based on point-to-point transmission from a single source to single a destination, e.g. video streaming and video on demand. The transmission can also be multicast[1] to a group of mobile users, where the content is made available to multiple subscribers. These modes are further detailed in section 3.1.

With mobile TV, the consumer can choose amongst different broadcast channels via interaction. This option provides the consumer with the possibility of choosing when the programmes will be watched. These TV programmes can be streamed to the mobile handset for viewing at the same rate as they are sent. They can also be downloaded from the internet and stored within the mobile handset for viewing at a later time.

There are different TV signal transmission mediums: *terrestrial*, *satellite* and *3G* networks which can deliver TV content to mobile users [3]. Amongst these mediums are broadcast mediums that have been evolved to provide TV broadcast services to the mobile environment. This includes MBMS, MediaFLO, ISDB-T, TDMB, and DVB-H. With these new technologies, millions of mobile users are able to watch and be in touch with their favorite events at any time and anywhere. These technologies are further detailed in section 3.5. Note that the satellite transmission is out of scope in this thesis.

Because it is quickly becoming a global standard and the leading technology for mobile television, DVB-H technology has come furthest along with a number of pilot projects taking place across the world, such as Germany, Italy, Finland, UK, France, United States and more. Following successful tests in different countries in Europe, the DVB-H transmission brought FIFA World Cup 2006 live on users' mobiles in for example Germany and Italy.

DVB-H and other broadcast technologies are not the only transmission mediums for mobile TV. Live TV and streaming video are also possible through 3G networks. Since its introduction, 3G operators were able to offer streaming video services and Live TV to their customers in different countries around the globe such as in the US, Japan, Australia and Europe. For instance, Telenor Norway were able to broadcast the 2005 Winter Olympics in Torino live to mobile users on its 3G network [3].

[1] The multicast transmission is out of scope in this thesis.

2.2 DRIVERS FOR MOBILE TV

Two main driving forces that influence the mobile television area have been identified – product development which has increased a consumer "pull" demand for TV services and technological development which has "pushed" a supply of TV services[2].

In recent years, the product development in the television market has changed. The boundaries of time and place are eroding, and the mobile consumers are increasingly having access to TV services wherever and whenever they want it. The Economist has accordingly pointed out two new trends within the television medium: time-shifting and place-shifting [4], for TV contents sent through mobile TV networks. Since its introduction on the market, the mobile telephone has changed many people's communication patterns, because of the new mobile networks and the introduction of new mobile telephones. This includes sophisticated technologies, better coverage, lower phone rates and broader service provision. Two network generations of mobile telephony co-exist on the Danish market, i.e. GSM and 3G. According to the European Commission's report, 90% of the Danish households have mobile phones[3]. This is a clear trend towards an increasing demand of services for mobile telephony.

The technological development on the other hand has changed the conditions for mobile telephony and the television medium. The first mobile networks generation provided analogue transmission and the possibility of voice signal transmission only. The second generation, GSM, brought a transition to digital transmission of the signals. This means better conversation quality and the possibility of data transfer services such as SMS and MMS. The third generation, 3G, brought a much higher transmission capacity in the network, and the evolution of mobile telephones has opened up the possibility of a rich variety of mobile services. In parallel to the development of the 3G network, a corresponding development of the mobile telephone's capacity has taken place. High-resolution colour monitors, digital cameras with up to three mega-pixels and up to 2GB memory are becoming more common. Digital terrestrial, cable and satellite TV transmission have increased the number of channels considerably. Furthermore, the consumer is no longer limited by when the programs are broadcasted. Storage media have made it possible to watch television wherever and whenever the consumer wants. The mobility of TV viewing will increase further with the introduction of mobile TV.

2.3 THE DANISH SUPPLY OF MOBILE TV

In Denmark, there are several different operators that offer GSM and 3G mobile telephony to their customers. Mobile television is one of the services on the market that requires the most network capacity. Therefore this thesis will only deal with operators who run their own high capacity network such as 3G and EDGE.

Today, four operators in Denmark match this requirement – TDC, Sonofon, Telia[4] and Hi3G Denmark.

- Since January 2007, TDC has been offering their customers six different television channels (http://tdconline.dk).

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[2] The idea of the demand and supply forces has been inspired from (Jonathan L,Sohil P, Maureen R,Chris

[3] EC National Report Executive Summary Denmark, spring 2005

[4] According to Annette Løvgren Larsen (Project Manager, Marketing BtC) Telia do not have any 3G sites but in fact Enhanced Data rates for GSM Evolution (EDGE).

  - The 24-hour music video channel *Voice TV*.
  - The public service channels *DR1* and *DR2* with their main output: documentaries, comedy and news.
  - *Kanal 4* showing mainly films, documentaries, some US drama shows, and sports.
  - The last two channels are *TV2 News* which is one of the 24-hour news channels in Denmark and *TV 2 Sputnik* which is an on-demand channel. With *TV2 Sputnik* a mobile user can buy a video clip for 5kr or buy a monthly subscription for 69kr.

  In addition, TDC mobile subscribers have two more options besides the monthly subscription: *pay-per-day* for 29kr and *per-week* for 49kr. Although the prices are much lower than the normal data call traffic, *Torben Rune,* Director of business consulting for Netplan, foresees that there will be no high demand for such services (InforMedia, Computerworld march 2007).
- Sonofon is also offering TV streaming to its customers. *TV2 NEWS*, *TV 2Sputnik* including TV2 news, sport, etc. Unlike the TDC mobile subscriber, a Sonofon mobile subscriber only has the option to pay a monthly subscription fee for the package which costs 25Kr.
- Since they upgraded their 3G network infrastructure to HSDPA in March 2007, the cellular operator Hi3G Denmark has been offering 15 live TV channels to their customers: *DR1*, *DR2*, *TV2*, *TV2 News*, *BBC World*, *Al Arabiya*, *ARD*, *ZDF*, *Nickelodeon*, *MTV*, *Bloomberg*, *TV2 Zulu* and MTV Shorts. The customer has also the possibility of choosing extra channels for 12 DKK a month, including *Fashion TV*, *CNBC*, *Al Jazeera*, *Deutche Welle* and *EuroNews*.
- Telia have not yet been able to offer TV services to their customers. According to their customer service department, they are expecting to launch TV services as soon as their EDGE network is upgraded to HSDPA.

2.4 MOBILE TV PILOTS

In this section, DVB-H pilots that have been conducted or are currently being taken place abroad as well as in Denmark are presented.

2.4.1 DVB-H Tests Abroad

"*The mobile TV market is heating up, with both tests and deployments accelerating over the next 12-18 months*" said David Linsalata, Research Analyst for Mobile Markets at IDC.[5]

Many mobile TV technical tests and pilot projects have been carried out or are currently underway in several different countries around the world. The aim of these pilots is to test the technical feasibility of different network equipment and terminals. In addition, valuable information can be gained on how the mobile users are adopting to the new technology and services and the way they interact and consume them.

The preliminary results from these pilot tests show a positive attitude towards mobile television. More than 10 DVB-H tests have taken place in Australia, Finland, Netherlands, Singapore, Malaysia, South Africa, France, Germany, Italy, the UK and in Pittsburgh. In the UK, the tests have been conducted by Nokia allowing 400 users

[5] http://www.modeo.com/press_05.asp

supplied with Nokia DVB-H enabled receivers to access 16 channels. This includes BBC, ITV, Channel 4 and others. While in the Netherlands, the first test took place in 2004 which was supported by Nokia and Nozema Services[6] [5]. The second test conducted by hundreds of users took place in Hague on July 2005.

In South Korea, about 30% of the mobile subscribers have expressed their interest in mobile TV based on the condition that the service is provided at an affordable price [6]. In Finland, the test has been conducted by 500 users accessing TV services using Nokia 7710 handsets. The result of the tests demonstrates that mobile entertainment is an important function for mobile television. It also reveals that the situations that are best suited for it are while people are traveling with public transportation or when people are waiting for something (Finnish mobile television pilot 2005). Moreover, the test has shown a very positive attitude towards Mobile TV, willingness to pay for the service and resemblances with the consumption patterns for traditional television. Table 2.1 shows the DVB-H test comparisons between Finland, the UK, France, and Spain.

	Finland	**UK**	**France**	**Spain**
Satisfaction	58% believe Mobile TV will be popular	83% are satisfied with the service	75% would recommend the service	73% are satisfied with the service
Willingness to pay	41%	76%	55%	68%
Daily viewing time	5 to 30 minutes per day	23 minutes per session with 1 to 2 sessions per day	Average 16 minutes	20 minutes
Popular content	Local programs from Finish national TV and sports	News, soaps, music, documentaries and sports	News, series and music	News, music entertainment, sports, documentaries, films

Table 2.1 DVB-H test comparisons (IBC, 2006)

2.4.2 DVB-H Tests in Denmark

In June 2007, TDC Denmark carried out pilot tests using the DVB-H standard to deliver video and data to mobile phones. The test was coordinated by Viasat while Nokia supplied mobile phones. In addition, TDC provides telephone services and Viasat provides broadcast services. The aim of the pilot was to test the technical feasibility of DVB-H transmissions as well as learning users' viewing experience and service acceptance. For more details please refer to the appendix A.

[6] http://www.nozemaservices.com/

3. OVERVIEW OF MOBILE TV TECHNOLOGIES

The technologies for normal TV sets have been designed for receivers with large screens where the power limitation is not a major issue. Mobile handsets have limited battery power, small screen size, a tiny built-in antenna and limited memory. Besides that, mobile handsets are meant to be used on the move at a speed up to 200km/h or more. In the presence of these limitations, the quality of the received transmission is not very good. Many technologies are being developed to provide mobile services today. They are also capable of providing to some extent extra features for the requirements of mobile TV transmission. They each have, however, both advantages and disadvantages.

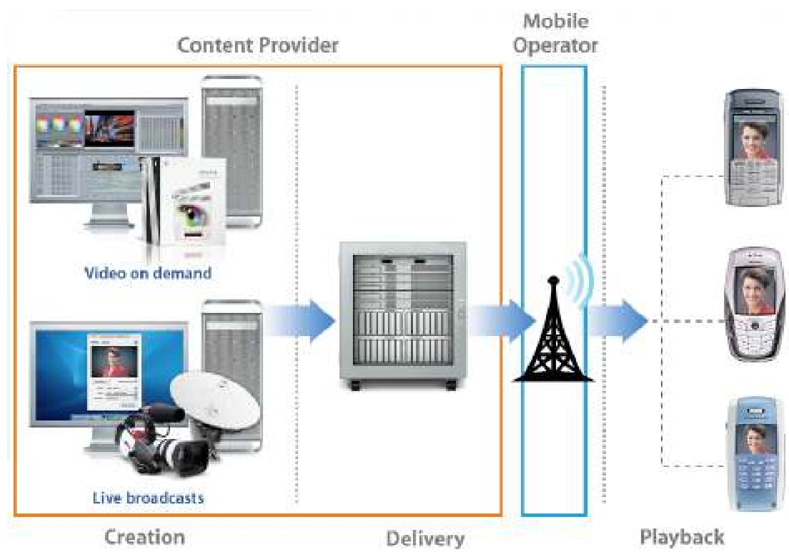

Figure 3.1 Content delivery on a mobile network[7]

The technologies that have now emerged are focused on the need to cope with the limitations of the mobile TV environment as well as the limitations of mobile TV receivers. The limitations of the mobile environment consist of mobility issues such as multipath effects, Doppler[8] and fading, whereas the mobile receiver limitations consist of low battery power and small gain built-in antenna.

Today, there are various mobile TV technologies which are trying to compete with each other to gain market share. They have different origins and have been developed for different aims. Some of these technologies complement each other, while others are in direct contrast to each other. In this section, a brief overview of these technologies will be given. Since DVB-H is leading so far in terms of tests and launches in Europe, this paper will put an emphasis on this technology and dedicate a whole chapter to it. More detail about DVB-H is found in Section 4.

3.1 BROADCAST AND UNICAST TECHNOLOGIES FOR MOBILE TV

There are two modes for content delivery to a mobile TV: *unicast* and *broadcast*. In the broadcast mode, the same content is made available for millions of users, while in unicast mode the content is delivered on demand to specific users upon selecting the

[7] Taken from one of the lectures of course 34631 “future mobile networks and services”, Henning Olsen
[8] “Doppler effect changes the frequency of the received signal when the receiver moves in relation to the transmitter” (www.dibcom.com)

content. In the following unicast and broadcast technologies are described in more details.

3.1.1 Technology of Unicast

Many Danish operators are already providing mobile television on *one-to-one* basis. With unicast, the possibilities of personalization are high since each viewer is reached with its own unicast stream. However the unicast networks have limitations in terms of number of users that can be supported within certain resources. For example, streaming video for certain events such as world cup football, which may be watched by thousands of users, may cause network saturation. This fact makes the scalability of such networks limited.

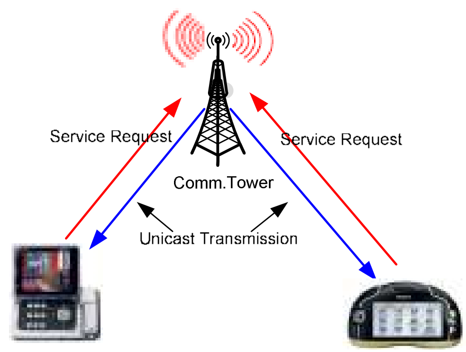

Figure 3.2 Unicast transmission for Mobile TV

Despite the fact that the unicast networks are not scalable, they can be suitable for video on demand. The latter provides the mobile users with the possibility to choose any TV content they like and whenever they want.

3.1.2 Technology of Broadcast

The technology that provides several viewers with the same content at the same time is called *broadcast*. Today's analogue broadcast of radio and television are two examples of broadcast. With that technology, possibilities of personalization are low, given the fact that all viewers receive the same content. However, it is appropriate for a mass market since there is no technical limits to how many viewers can receive the content at the same time.

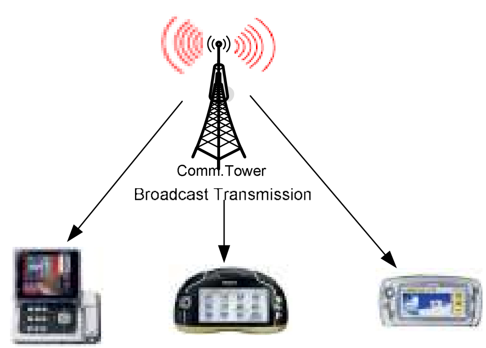

Figure 3.3 Broadcast transmission for Mobile TV

Nowadays, various broadcasting technologies do exist on the market. For example, a technology that is standardized for the 3G network is referred to as MBMS, Multimedia

Broadcast and Multicast Service. These networks can deliver higher data rates to send out the same program to several viewers from 64 to 256 kbps using MBMS/UMTS protocols [6]. This technology, however, can use up to 30% of the capacity of the cellular network. This has an impact on the capacity of the 3G cellular networks which may deteriorate the quality of the traditional telephony service for which it was originally designed.

Parallel with the development in the mobile networks, a technological change is taking place within the traditional television sector from analogue to digital television broadcast. A standard for digital television that has been developed in recent years is called DVB-T (Digital Video Broadcast Terrestrial) which has been designed for the TV transmission to TV sets at home. Its successor standard for the mobile version is called DVB-H (digital video Broadcast for Handhelds) which has emerged to fill the gap that was left by DVB-T with extra features to extend the TV transmission from stationary TV sets to mobile handsets. More detail about DVB-H is found in section 4.

3.2 MOBILE TV USING PODCASTING

Today, mobile phones with MP3 players are continually offered with larger batteries and higher capacity storage. Audio and video podcasts[9] adapted for these handheld MP3 players are available on the internet. The technology, where sound and video files containing radio and television programmes is available for download, is called *podcast*, a word that has its origin in Apple's popular *iPod* handheld media player [7]. TV programmes and other multimedia services consumed through *podcast* constitute one substitute to mobile TV. With podcasting the mobile users can download video podcast on his handheld and watch it offline whenever is convenient to him. The video podcast can also be streamed at the user's convenience at anytime and anywhere.

3.3 MOBILE TV USING WIRELESS TECHNOLOGY

Wireless networks are gaining widespread acceptance around the globe. They are considered as potential carriers of multimedia services in general and mobile TV services in particular. In this section two popular wireless technologies are presented WiFi and WiMax.

3.3.1 Mobile TV Using WiFi Technologies

Wireless Fidelity networks WiFi (802.11x) are increasingly gaining popularity in providing Internet access. It started as a replacement of local area network (LAN) cable for a public access means. The number of WiFi hotspots is increasing; WiFi networks are nowadays being used in public areas such as home, cafes, hospitals hotels and airports.

WiFi allows higher transmission rate than any mobile network technology [8].The most popular WiFi 802.11b standard can offer up 11Mbps, while the newer standard 802.11g which is backward compatible with 802.11b can offer up to 54Mbps [8]. Due to the higher transmission that can offer, WiFi is expected to complement the mobile networks such as 3G.

With growing popularity of WiFi technology, it is considered as another means for mobile TV transmission. It would be interesting, for instance, to stream and watch short

[9] Podcats are recorded audio and video programs available on the internet

You-Tube video clips on the handset while sitting in the airport waiting for the flight or in the hotel while waiting for dinner to be served. With WiFi the mobile user can also download TV contents through the Internet using his mobile handsets. The content can then be viewed offline when the mobile user is on the go.

Additionally, WiFi is cost effective, because it requires no network licenses. Besides, it is relatively cheap to implement and run. Despite all these facts, there are still issues that need to be resolved such as seamless roaming between WiFi and cellular networks and billing [9]

3.3.2 Mobile TV Using WiMAX Technologies

WiMax (Worldwide Interoperability for Microwave Access) is a technology that enables the transmission of data services in a wider area than WiFi can cover. It also offers more capacity, which makes it more expensive than WiFi. WiMax is ideally suited for multimedia content and video transmission[10]. It provides a high-speed wireless internet access service while the receiver is in motion at a speed up to 60km/h [3]. The typical applications for WiMAX are audio and video on demand. With WiMax, the mobile consumer can download or watch a live video stream while he is in motion, on the train, in the car or similar.

As opposed to WiFi, seamless roaming between WiMax and mobile networks is rapidly becoming possible, and the mobile handsets are able to switch over from a mobile network to wireless connections [9]. However the drawback is that WiMax uses a spectrum that requires a network licence to run, unlike WiFi.

Additionally, WiMAX can offer a higher speed of more than 20 Mbps and high coverage of an entire city with a few transmitters [3]. WiMAX comes in two flavors: fixed wireless access WiMAX (IEEE 802.16d) which provides data rates of 70-100Mbps, and mobile WiMAX (IEEE 802.16e) based on OFDMA modulation. The latter provides a data rate up to 15Mbps over a range of around 10 km which can allow mobility at a speed of 150 km/h [3].

Furthermore, the advantage of WiMAX and WiFi is that they both offer unicast point-to-point as well as broadcast content delivery within one network. This makes them ideally suited for mobile TV broadcasting, video streaming, as well as video-on demand with possible interaction for mobile user [9].

3.4 MOBILE TV USING CELLULAR NETWORKS

The inceptions of 2.5G technologies with their higher data rate have permitted the mobile operators to provide multimedia services. This includes video, audio streaming and downloading in the same way IP streaming and file downloading are handled over the Internet. However, due to the network and transmission conditions, the video clips were delayed a few seconds and the video quality was not acceptable due to low frame rates [3].

[10] http://www.sportelmonaco.com/var/gallery/document/press/Numero2.pdf

The leap from 2.5 to 3G increased the data rate and the evolution of the video, and audio protocols along with the efficient coding under MPEG-4[11] led to the offering of live video channels by 3G carriers at speeds of 128kbps or more [3].

The 3G networks have been designed to provide higher data rates, which can go up to 384 kbps [3]. The 3G networks are being used for mobile TV services due to the large bandwidth available for 3G. Currently, 3G networks are deployed in different countries over the world as well as in Denmark. However, due to the limited bandwidth available in these networks, they are not optimized for the delivery to a large number of simultaneous users and hence not ideally suited to deliver compelling TV services.

The 3G-based mobile TV services can provide mobile data streaming at an acceptable level of rates up to 300kbps which is equivalent to around 10 calls on the network [3]. That means the 3G network has to give up 10 calls to offer one video streaming. This however, does not make TV broadcast the best application for 3G networks, especially when it comes to watching important events which could be watched by millions of users.

New technologies are being developed under the 3G partnership project (3GPP) to extend the speed, coverage area and range of services that can be provided on the 3G networks. High Speed Downlink Packet Access (HSDPA)[12] and Multimedia Broadcast Multicast Service (MBMS)[13] are examples of such technologies evolved to support audio and video services.

Several Danish operators are planning to upgrade their networks' infrastructure during 2007-2008 to a new standard, HSDPA. Under normal conditions, the HSDPA network is able to deliver 384kbps to up to 50 users in a cell area [3]. For the consumers to be able to use the new technology for mobile television, they need to have HSDPA enabled phones or must upgrade their phones to HSDPA, something expected to be gradually offered with new telephones during the next couple of years.

For example, TDC is rolling out HSDPA[14] or as they call it Turbo 3G on top of its existing 3G network. With Turbo 3G, TDC can offer download speeds as high as 3 Mbps in large cities such as Copenhagen, Odense, Aarhus, and Aalborg. In other cities, speeds will be up to 1.5 Mbps. According to their plan, the Turbo 3G network will cover 80 percent of the Danish population by the end of 2008 [10]. In addition, Hi3G Denmark operator has also upgraded their network to HSDPA in March 2007[15].

"*With the upgrade to Turbo 3G, TDC has paved the way for the fully mobile broadband network. If you have a cell phone supporting Turbo 3G, the higher speeds mean faster downloads of TV shows, music, and all the other content services offered by TDC to the cell phone,"* says Mads Middelboe (inset) , President of TDC Mobile.

[11] MPEG-4 is a new standard for video compression in which the pictures are even highly compressed than in MPEG-2. This results in a significant improvement in network throughput and less bandwidth usage which makes it ideally suited to be used in a mobile broadcast networks.
[12] Is an evolution of 3G technology for the carriage of higher data rate, it can extend the bit rate to 10Mbps or even greater on 5MHz 3G networks [3].
[13] Is a new technology designed to overcome the limitations of 3G networks for carrying live channels.
[14] Is also known as Turbo 3G.
[15] This information has been provided by 3 customer service.

Despite the fact that it offers high speed data rates, the disadvantage[16] of 3G networks, even with an upgrade to HSDPA technology is still scalability. The unicast network does not scale well as the number of users accessing the service grows. Figure 3.4 shows the capability of the HSDPA network to supply several users simultaneously. It is clear from the figure that the user satisfaction decreases with the increase of network traffic caused by the number of users accessing the network simultaneously.

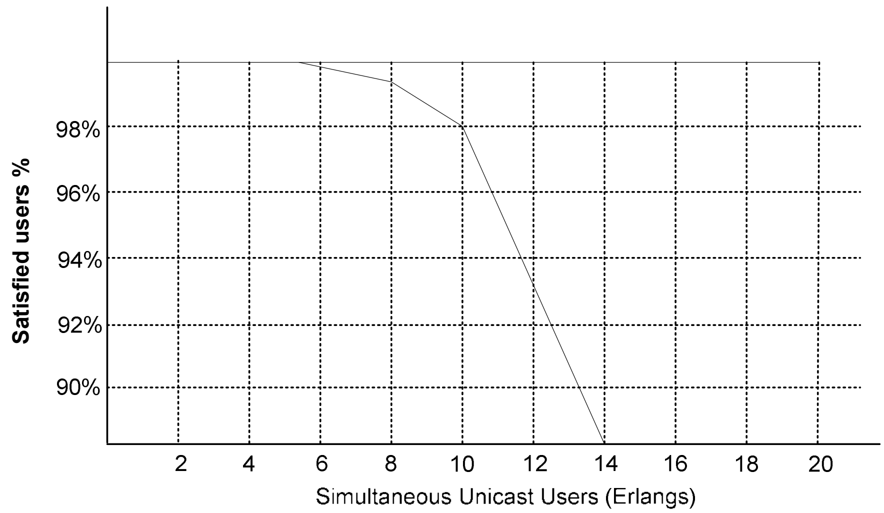

Figure 3.4 Capability of HSDPA network to cater simultaneous users [3]

3.5 MOBILE TV SERVICES USING DIGITAL TERRESTRIAL TRANSMISSION

Broadcast transmission networks are really important due to the high power the terrestrial transmitters can provide. This includes indoor as well as outdoor areas extending to around a 30-km radius [3]. The high power the terrestrial transmitters can provide makes them suitable for indoor reception and hence ideally suited to TV transmission on mobile handsets.

There are four different technologies using terrestrial transmission for mobile TV services. These technologies are competing each other in gaining market share. This include European standard DVB-H, Korean led T-DMB, Japanese ISDB-T and Qualcomm's MediaFLO. In terms of tests and launches, DVB-H is supposed to be the leading standard in Europe at the present time. This standard is discussed into more detail in section 4, while the rest of the other technologies are explained briefly in the following.

3.5.1 MediaFLO Mobile TV Services

MediaFLO (Forward Link Only) is a bearer technology developed by Qualcomm[17] for broadcast transmission to handheld devices using OFDM modulation. Since it holds a license in the 700-MHz frequency band, Qualcomm intends to roll out the services in

[16] The main advantage however, is that HSDPA is built on top of existing 3G infrastructures. Therefore the mobile network operators can use their 3G licenses without investing in new frequencies. Besides the network infrastructure is already in place which requires only to be upgraded to HSDPA for low cost.

[17] Worldwide company that specializes in wireless and cellular telephony (centered in San Diego, California, USA) - babylon dictionary.

this part of spectrum. It uses UHF, VHF, or L-band spectrum over channel bandwidths 5, 6, 7, or 8 MHz channel bandwidths [11].

MediaFLO has been designed to provide multimedia contents to a large number of mobile subscribers such as mobile TV services as well as audio and video streaming. It handles power consumption for mobile handsets the same way that DVB-H does. The power saving mechanism is discussed in more detail in section 4.5.1. The most interesting thing is that FLO transmitters can be set apart 50 km due to the high power transmission they can offer. Three or four FLO transmitters can cover a large metropolitan area [3].

3.5.2 Mobile TV Using ISDB-T Services

ISDB-T (Integrated Services Digital Broadcasting Terrestrial) is a terrestrial television standard developed in Japan. It provides TV broadcasting to mobile handsets. This includes multimedia services, video and audio transmission. ISDB-T has until now, as opposed to the previous discussed technologies, remained a Japanese technology, launching its services only in Japan. Similar to DVB this technology uses a MPEG-2 video transport stream and has a bandwidth of 5.6 MHZ [3]. Furthermore, the ISDB-T uses OFDM with digital modulation schemes such as QPSK, DQPSK, 16QAM and 64QAM [3]. This makes it suitable for different operating conditions and particular needs.

Similar to DVB-T, ISDB-T uses the COFDM[18] modulation which makes the signal transmission robust against the multipath effects and signal interference. Moreover, the ISDB-T systems support the 4K modulation OFDM mode in addition to the existing 2K and 8K modes [3]. It is supposed to be ideally suited for mobile reception. The 4K mode is further detailed in section 4.5.4.

3.5.3 DAB, DMB and T-DMB Technologies

Digital Audio Broadcasting (DAB) is a replacement for traditional Frequency Modulation (FM) (*An Introduction to Digital Radio, November 2005*). The DAB offers high quality audio and data to DAB receivers using digital TV broadcasting transmitters. It has been designed to provide reliable delivery of digital multimedia services for fixed, mobile and portable receivers. The specifications for mobile TV broadcasting were initially developed for DAB in the late 1990s within the European Eureka 147 project [12]. Since DAB services have been allocated spectrum[19] in many countries, the multimedia broadcasting services and mobile TV were introduced through the digital multimedia broadcasting (DMB) standard which is an extension of DAB standards. The DAB standard was then modified by adding an additional layer of error correction to handle multimedia services [3]. The resulting standard was then renamed to Digital Multimedia Broadcasting DMB. Because it uses the same spectrum as allocated for DAB, the rollout of the DMB was easy and successful [3].

[18] Coded Orthogonal Frequency Division Multiplexing is a modulation scheme that has been designed to combat the effects of multipath interference for mobile receivers. Its main advantage is resilience to errors as the data is spread over multiple carriers [13].

[19] DAB standard can provide up to around 1Mb/s of multiplexed audio data in a RF bandwidth of approximately 1.7MHz [11] and can be operated at any frequency up to 3GHz for portable and mobile reception [12].

In addition, DMB was deployed in Korea first and recently in European countries such as Germany and the UK. It was introduced in Korea using terrestrial broadcast which has been deployed in VHF band III[20][3]. DMB services come in two flavors: S-DMB and T-DMB [3]. The S-DMB is based on mobile multimedia broadcasting to handheld devices via satellite[21]. The mobile TV services are delivered via high powered satellites with a transmission in S-band. To ensure indoor reception, buildings are empowered by S-band repeaters to rebroadcast the signal terrestrially. On the other hand, T-DMB service divides the 6 MHZ VHF slot into three carriers of 1.54 MHz each. Each of these carriers can carry two to four video channels and additional audio channels. Despite the fact that the handsets can be used at speeds more than 250km/h in the VHF band, T-DMB does not have any feature for the support of power saving which is still a critical issue for low battery life for mobile handsets [3].

Furthermore, the commercial launches of DMB, including free-to-air services, started in December 2005 in Korea. Launches started in Germany in May 2006, providing free-to-air and subscription services covering 15 million users [12].

3.5.4 DVB-T Digital Terrestrial Broadcast Television

Digital Terrestrial Broadcast Television is the European consortium DVB standard for digital terrestrial TV. This system uses MPEG-2 multiplexed video and audio carriers. DVB-T uses the same spectrum (UHF and VHF bands) used in analog TV, where each channel slot can be used to carry three to five digital channels as oppose to one channel for analog TV [3], see Figure 3.5.

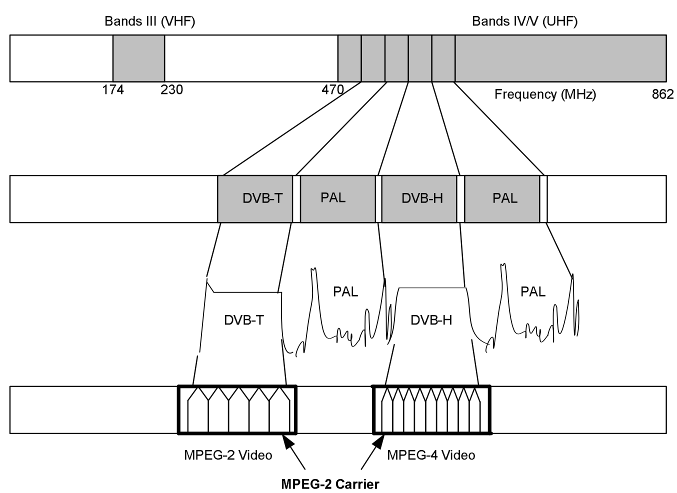

Figure 3.5 Terrestrial TV [3]

With DVB-T, the transmitted data is spread across a large number of closely spaced carriers using 2K or 8K modes. This technique makes the DVB-T signal insusceptible to the reflected signal, echoes and inter-symbols interference. However, the main difference between the two modes is performance with echoes and separation of the transmitters in the Single Frequency Network (SFN)[22]. This performance is determined by the guard intervals available in these modes.

[20] 174–230 MHz: Band III Television (channels 4–11) (wikipedia.org)
[21] Please note that the satellite-based mobile TV delivery is outside the scope of this thesis.
[22] "A single-frequency network or SFN is a broadcast network where several transmitters send the same signal over the same frequency channel simultaneously. The aim of SFNs is efficient utilization of the

With COFDM, the total symbol period consists of active interval (symbol period) and guard interval. Figure 3.6 illustrates the total symbol period with the guard interval. The guard interval provides protection against data loss and interference caused by propagation delays. If the echoes fall within the guard interval, they will be added constructively by the receiver, whereas if the echoes fall outside the guard interval they will be interpreted as noise and these signals will not be decoded by the receiver. Therefore, the guard interval stands as a parameter that determines the signal's tolerance to echoes. This ability to withstand echoes governs also the size of the single frequency network, because larger guard intervals allow for longer distance interference to be tolerated [15]. However, the longevity of the guard interval has a certain limitation, because a longer guard interval also lowers the data rate and thereby reduces the channel efficiency.

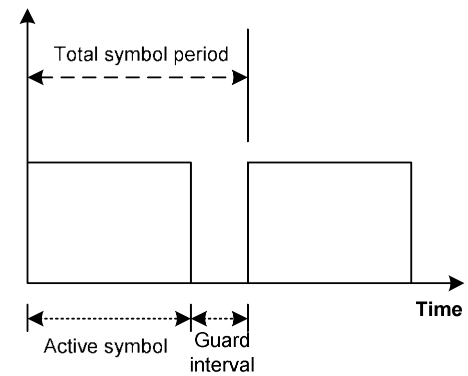

Figure 3.6 Total symbol period

In addition, the available data rate for a broadcast will be affected by choosing between 2k and 8k systems within the COFDM signal. Selecting 8K mode, the guard interval duration will increase by a factor of four times the in 2K system. This also means more tolerance to echoes and multipath performance improvement than the 2K system can tolerate. On other hand, the distant separation between the transmitters in SFN can be four times larger than with the 2K system [15].

DVB-T uses CODFM modulation with different modulation schemes such as QPSK, 16QAM or the 64QAM carrier modulation. It uses the Ultra High Frequency (UHF) spectrum which can be used with 6, 7, or 8 MHz channel bandwidths [3].

Furthermore, DVB-T transmission has proven its ability to serve stationary and portable TV sets, including to some extent support of mobile reception with certain parameters [16]. The major drawback with DVB-T is a high power consumption requirement which can be inefficient for battery-powered mobile handsets. Another drawback is the poor signal reception due to the small built-in antenna with a low gain on mobile handsets.

These limitations however, have been addressed by DVB in the new developed standard DVB-H dedicated for mobile handsets. This standard is an enhancement of

radio spectrum (only one frequency is required in each area), allowing a higher number of radio and TV programs in comparison to traditional multi-frequency network (MFN) transmission" (www.wikipedia.org). The MFN network is out of the scope in this paper. The drawback of SFN however, is that the information transmitted from all the transmitters in the SFN cell has to be the same which limit the network capacity [14].

DVB-T to support additional features suitable for TV broadcast on mobile devices. Because it is the best delivery system available on the market, this thesis will put a special emphasis on this technology. This standard is further described in section 4.

3.6 COMPARISON OF POPULAR TV SERVICES

In fact it is hard to say which technology is better, especially since the mobile services are offered based on a number of constraints such as availability and spectrum. However, according to Amitabh Kumar [3] the parameters that are important in the evaluation of the technology are presented as follows:

- QOS for indoor and outdoor reception
- Power consumption
- Roaming
- Efficient spectrum utilization
- Costs
- User requirements such as service availability, handover and type of handset.

The following Table 3.1 describes both the advantages and disadvantages of the currently available different technologies that provide live TV services on mobile handsets.

Table 3.1: comparison between technologies

	Advantage	Drawback
T-DMB	• Attractive price as the mobile consumers will be able to access TV programs for low or no cost. Due to the fact that providers of T-DMB services prefer to use revenue-generating advertisements • Lower channel switching • Higher frame rate(30fps) • Uses existing DAB frequency	• T-DMB has limited coverage area size to a large city. Indoor and underground reception is not guaranteed and the number of channels that can be provided is small compared to what DVB-H can do. The major handicap of the T-DMB technology is the power consumption which has a great impact of the usability and user acceptance of the T-DMB services.
ISDB-T	• ISDB-T provides transmission both for fixed as well as mobile reception • The transmission is a continuous stream which minimizes signal delay acquisition when the subscriber switches between channels	• The transmission is a continuous stream. This means that the receiver needs to be power-on all the time. This results in high power consumption which has an impact on user acceptance of the service.
MBMS	• MBMS re-use of the 3G cellular spectrum is one of the key advantages of this technology. That means no spectrum reassignment	• Transmission capacity to MBMS-base services supports a bit rate of 64kbps which seems to be adequate for some channels such as news channels

	needed to acquire for mobile TV services. • MBMS reduces implementation costs both for the 3G network and 3G handsets as the platform already in place and handsets are available on the market. • Scalability compared to unicast streaming video services • Security, access right and roaming already exist • No need for partnerships with network broadcasters	applications, but it seems inadequate for sport channels which require at least 128kbps to ensure an acceptable level of SQ. • Supports higher bit rates up to 256kbps. This results in a decreasing number of channels available per cell.
MediaFLO	• MediaFLO provides channels switching in 2 seconds. • Qualcomm has acquired a license in the 700MHZ spectrum in an auction in 2004. The advantage is high power transmitter with relatively low frequency, which results in a small number of towers required to serve large areas.	• Due to its proprietary nature, it will have limited success outside US markets
DVB-H	• European standard approved by ETSI. • DVB-H being compatible with DVB-T can share the same frequency bands. It extends from 470-862[23] MHZ in Europe, band 1670-1675 MHZ in US and 700MHZ ranges can also be used. • DVB-T infrastructure already in place can be shared with DVB-H (cost-effective). That means only some extra investment is needed to allow reception in more challenging locations	• While time slicing feature is a key factor of power saving, it may have an impact on the viewing experience. This is due to the fact that time slicing can cause signal delay when the user attempts to switch from channel to channel on his handset. • Existing handsets need to be upgraded to support DVB-H • Currently the spectrum available is limited.

[23] It is said to be technically the most optimal band for Mobile TV. Figure E.5 in the appendix E, explains the reason for this preference over VHF and High UHF bands.

Figure 3.7 below depicts a worldwide forecast of mobile TV users by technology. As can be seen from the figure, the DVB-H technology is the leading technology with high acceptance among mobile TV users. The other technologies share almost the same rate of acceptance with T-DMB which is first, second ISDB-T and then S-DMB. We see also that the TV analogue technology will already begin to loose acceptance amongst its users before 2010 when this technology is expected to phase-out from the market. Consequently, the frequency range that will be released can then be used for DVB-H.

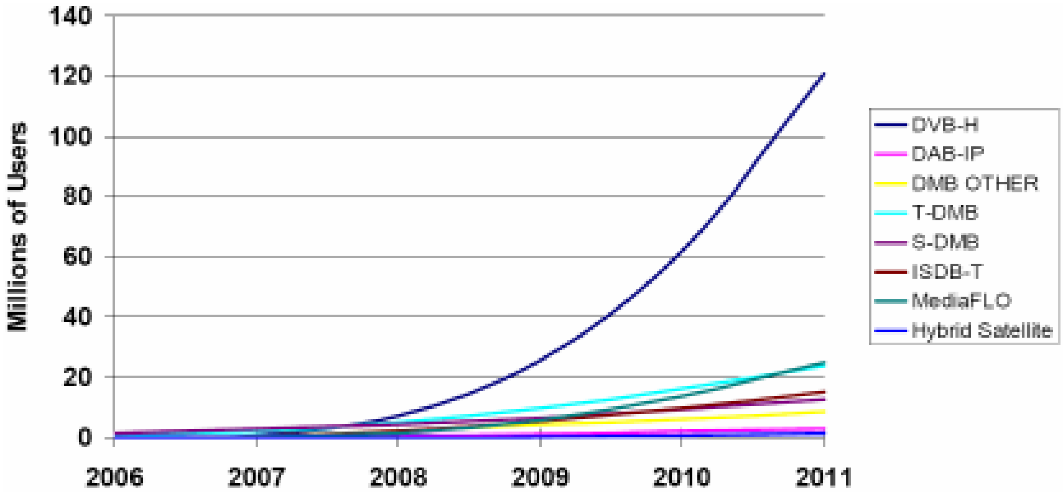

Figure 3.7 Worldwide forecast of Mobile TV users by technology (IBC, 2006).

4. TECHNICAL ASPECTS OF DVB-H

This section discusses the technical aspects of DVB-H. First, an introduction of DVB-H is presented, and then questions about why this technology is necessary and how it works are answered. This is followed by a presentation of the difference between DVB-H and its predecessor, the DVB-T standard. Finally, the new features of DVB-H that have been added to DVB-T are described.

4.1 WHAT IS DVB-H?

Digital Video Broadcasting to Handheld (DVB-H) is a technology that has been designed for mass distribution of multimedia contents to wireless handheld terminals. DVB-H has been standardized by the DVB and European Telecommunications Standards Institute (ETSI) in November 2004[3]. DVB-H introduces some key differences and adds extra features to DVB-T – such as time slicing and forward error correction. These extra features, as we shall see in section 4.4, are the key factors which extend the transmission of TV signals from the stationary TV sets at home to DVB-H-capable mobile handsets. Figure 4.1 depicts a conceptual view of a DVB-H receiver.

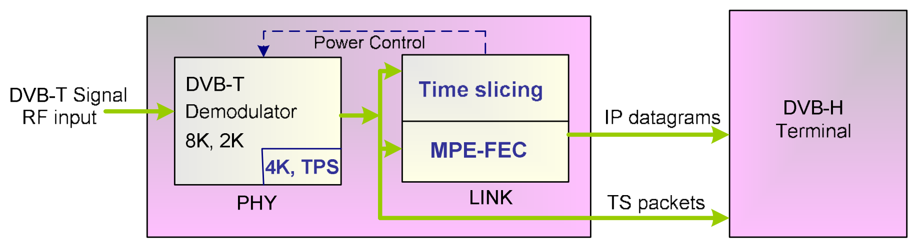

Figure 4.1 Conceptual view of DVB-H receiver [15]

DVB-H has been designed to meet different objectives:

1- Reaching unlimited number of users
2- High power transmission so that indoor reception can be guaranteed
3- The access to services should be possible not in only indoor and outdoor areas but also while traveling at various speeds by car, train or similar.
4- Reduce power consumption to compensate for limited battery life of the mobile handsets
5- Seamless frequency handover to ensure non-interrupted access to services while the mobile user moves from one transmission cell to another.
6- Use the same spectrum as terrestrial broadcast and flexibility to be used in different transmission bands and channel bandwidths so that it can to be used in different parts of the world.
7- Robust coding schemes and error correction to meet the requirements of the mobile environment where the signal strength is highly variable.
8- Maximum compatibility with DVB-T to ensure minimum cost through re-using the existing DVB-T network infrastructure.

DVB-H can provide in one DVB-H multiplex between 20 and 40 channels or more depending on the bit rate for millions of viewers [3]. While DVB-T services are delivered at rates up to 24Mbps, DVB-H services can be delivered to mobile handsets at data rates up to 11Mbps [3].

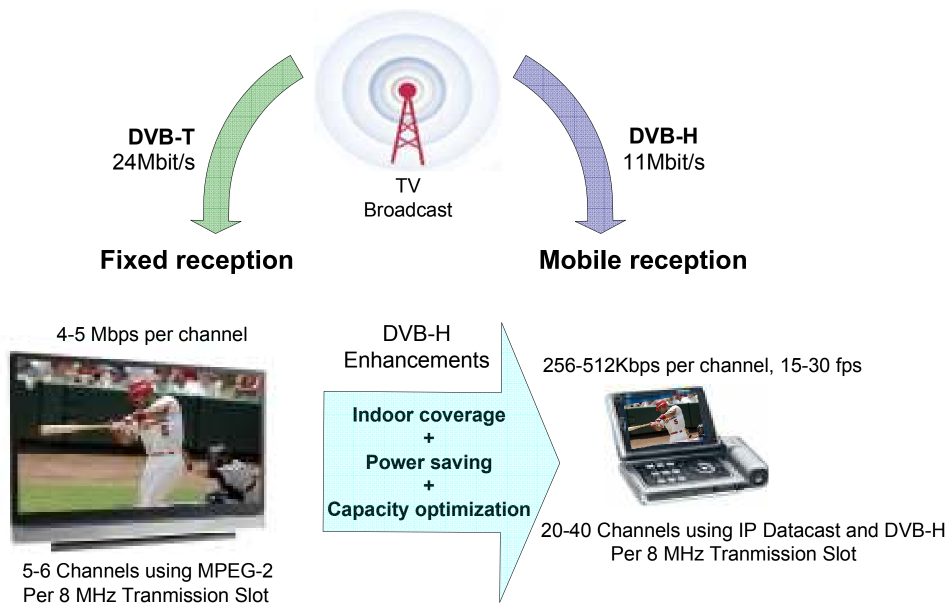

Figure 4.2 DVB-H Transmission System

In addition, DVB-H is backward compatible with DVB-T which means that DVB-H can run on the exiting DVB-T infrastructure. It also follows IP datacast which makes the entire end-to-end DVB-H system IP network [2]. That means that the mobile users can also have access to any content that can be sent over the internet. This includes web pages, games, music and audio as well as video streaming. The IP-Datacast is further detailed in section 4.5.7.

4.2 WHY DVB-H?

"*Consumers are demanding more content, such as live TV, from their mobile devices, and open procedure standards are key to delivering that content in a cost-effective way,*" said Kevin Jones, Director of Business Development for Intel's Mobility Group. "*DVB-H is a very effective way to deliver high-quality, broadcast digital TV to mobile users*" [17].

With a successful replacement of analog TV with Digital TV transmission, digital video broadcasting terrestrial transmission is being adopted in many countries around the world. As the analog TV is being phased-out with the deployment of digital TV broadcasting, the spectrum is being freed up. While one channel used to occupy one frequency slot in analog transmission, a single multiplex in DVB-T transmission can carry from six to eight channels [3]. With such success of DVB-T terrestrial transmission for TV sets, it was considered a viable option to have these services available on mobile handsets. This has been achieved by introducing suitable modifications to DVB-T standards.

Although DVB-T transmission has proven its ability to serve fixed, portable and even to some extent mobile handsets, DVB-T services are not ideally suited for mobile devices. The DVB-T technology has been designed for video transmission to TV sets at home with a large antenna placed on the roof and no limited power consumption on the receiver [2]. These factors made DVB-T unsuitable for a mobile environment where mobility is the main issue which is affected by low signal strength and signal fading.

The other driving factors for DVB-H is the cellular networks such as UMTS or 3G networks. These networks as has been mentioned earlier are not scalable to deliver mobile TV contents to millions of users. They have limitations using network resources to serve multiple television programs to a large number of users simultaneously. Even though these limitations to some extent have been addressed by IP multicast systems, such as MBMS and HSDPA, the digital video broadcast technology for handheld devices is far better in terms of delivering true mobile TV in a mobile environment with reasonable service quality [3].

4.3 HOW DOES DVB-H WORK?

The digital signal sent to TVs in people homes by DVB-T content producers is an MPEG-2 transport stream whereas the signal sent to mobiles is transmitted as IP packets from a DVB-H content producer. The signal then is sent to the broadcast provider who is thus able aggregate the content and adds new information such as commercials, TV programming information, text-TV, ect. This is then sent to the broadcast network operators which are in turn able to broadcast it to the users. These companies are the technical players, in this context, which provide the actual transmission service as well as providing the technical air interface to digital TV sets [2].

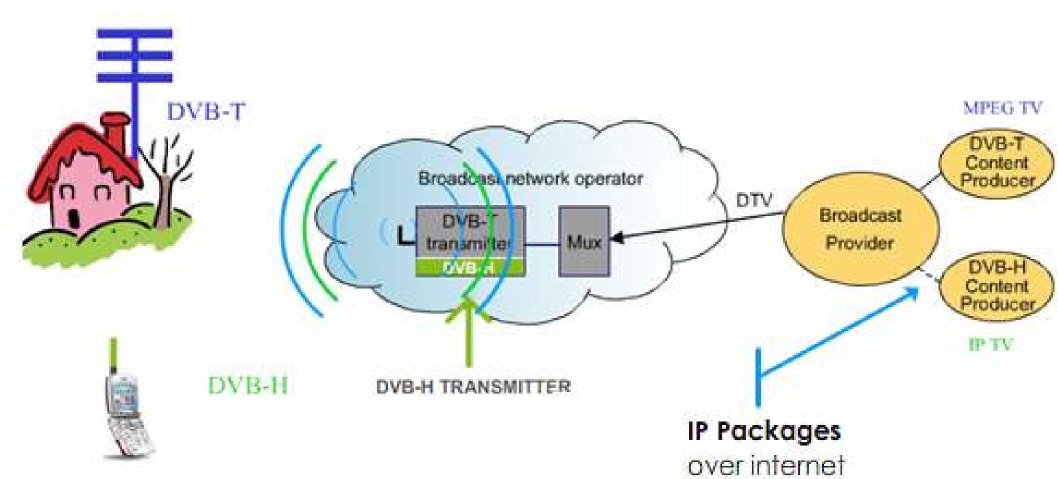

Figure 4.3 Overview of DBH-H and DVB-T transmission [2]

Video transmission in DVB-H is carried out using the Advanced Video Encoding (AVC) codec such as MPEG-4 for coding video signals [3]. Being based on an IP layer, DVB-H can support any other audio and video coding format than MPEG-4. Another advantage is that mobile users can have access to other contents and applications such as games from the Internet, HTML/XML files as well as audio and video clips.

With DVB-H, video and audio services can be encoded by different encoders. The encoders are connected through an IP switch to an IP encapsulator (IPE). The latter combines all the audio and video services along with the service description such as the electronic service guide EPG into IP frames. It then converts the IP streams into DVB transport using Multiprotocol Encapsulation (MPE), organizes channel data into time slices and adds MPE-FEC when needed [3]. Time slicing, as we will see in section 4.5.1, allows the receiver to be active only when the selected channel is expected to be received.

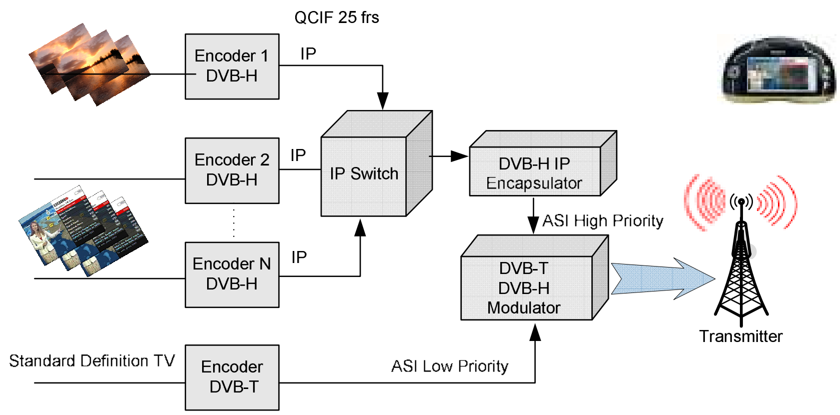

Figure 4.4 DVB-H Mobile TV Transmission System [3]

To make the transmission more robust in a mobile environment, the IP encapsulator provides reliable signals in a mobile environment using advanced forward error correction. The output of the IP encapsulator is then modulated using the COFDM modulator with 4K, 2k or 8K carriers. Table 4.1 below shows the number of COFDM subcarriers that corresponds to each mode.

Carrier mode	Number of carriers
2k	1705
4k	3409
8k	6816

Table 4.1 Carrier modes with the corresponding number of carriers [18]

The COFDM modulation provides immunity to signal fading and Doppler effects in a sensitive mobile environment [3]. The 4K mode has been considered part of DVB-H standards because the 2K carrier mode does not provide protection against selective frequency fading[24]. Besides, the guard interval requirement in this mode is suitable only for small cell areas for SFN. On the other hand, in the 8K carrier mode, carriers are placed too close in frequency which makes the Doppler effects significant and not suitable for mobile receivers. Therefore, the 4K mode is a trade-off between cell size and Doppler effects due to mobility.

Furthermore, the COFDM modulation in DVB-H is suitable for SFNs where all the transmitters in a certain area operate synchronously through GPS-based time clocks [3]. The repeaters can also be used to enforce signal strength and video reception in critical areas such as indoor and underground areas. In addition, the modulation used for each carrier can use any of the modulations, QPSK, 16QAM or 64QAM [15].

4.4 DVB-H vs DVB-T

There are various reasons why DVB-T is different than DVB-H. DVB-T was designed for digital TV transmission signals to stationary TV set receivers. The TV sets as we all

[24] The frequency selective fading is a consequence of destructive interference of the radio signal by itself due to multipath reflections (www.dsprelated.com)

know are plugged into either 220 or 110 volts, stable power supply. The table below describes the difference between the conditions in which DVB-T and DVB-H are used.

	Digital TV over DVB-T	IP Datacasting over DVB-H
Display	Large TV screen	Smaller, mobile phone screen
Antenna	Large, roof-top	Internal
Power Supply	Fixed, continuous	Battery powered limited
Reception mode	Fixed, continuous	Mobile

Table 4.2 Comparison between DVB-T and DVB-H technologies

In DVB-H, the digital TV is sent as IP packages over IP network, whereas in DVB-T the digital TV is sent as an MPEG-2 continuous stream. Only 128 to 384 Kbps per TV program is required for the IP-based DVB-H to deliver high quality video on mobile handsets. This means that 50 to 80 TV programs can be broadcasted over the network. By contrast, the DVB-T technology, which was designed for large screens, can deliver only 3 to 5 TV programs over the same network [19].

Furthermore, DVB-H has been designed to support indoor as well as outdoor coverage for mobile devices with small built-in antennas. DVB-T supports outdoor reception with a large rooftop antenna for the receivers and is not ideally suited for indoor reception.

Additionally, DVB-T standards are not suitable for mobile environments due to the Doppler effects[25]. Therefore a special modulation technique, the COFDM 4k carriers, has been adopted in DVB-H to cope with this limitation. In a mobile environment, the signal is exposed to variations such as interference, signal fading, and high level of man-made noise. However, this has been handled in DVB-H using the error correction technique MPE-FEC to ensure robustness. More detail about MPE-FEC is found in section 4.5.3.

Another difference between the two networks is that the transmission of TV signals in DVB-T are constant streams, while in DVB-H receivers, the receiver can sleep and save battery power up to at least 90 percent. The key solution is that in DVB-H, the TV signal is transmitted in time slicing. This extra feature is further detailed in 4.5.1.

Figure 4.5 below describes the power consumption of DVB-H versus DVB-T receivers. It is obvious from the figure that, regardless of the evolution of DVB-T, it has not yet achieved in terms of power saving what DVB-H has.

[25] The 8K carriers used for COFDM modulation appear at frequencies different from the intended at the receiver end.

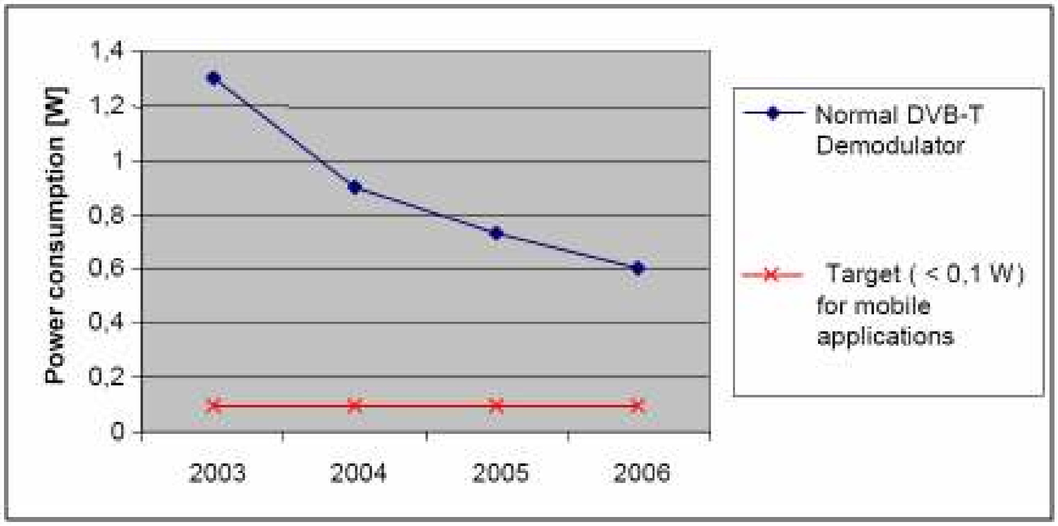

Figure 4.5 Power consumption of DVB-T and DVB-H receivers [20]

Although there is a difference between DVB-H and DVB-T, they are compatible in the sense that they share the same physical layer, modulators and transmitters. This is an advantage for DVB-H because it can be built on top of the existing DVB-T infrastructure, which may reduce the overall network investment. More details about network scenarios can be found in section 5.

4.5 TECHNOLOGY OF DVB-H

DVB-H was designed for TV broadcasting on handheld devices. It adds on extra features to DVB-T to meet the requirements of the mobile environment. DVB-H and DVB-T share the same physical layer which makes DVB-H backward compatible with DVB-T. It can carry the same MPEG-2 transport stream and uses the same OFDM modulator as well as the same DVB-T transmitter. The capacity of the multiplex can be shared between DVB-T and DVB-H where twenty to forty channels can be transmitted in a single multiplex [3].

Furthermore, DVB-H was designed to integrate into existing DVB-T networks and share its infrastructure. This makes it an ideal technology for upgrading the DVB-T network as it requires lower cost and less time to market. In addition, DVB-H overcomes all the limitations which DVB-T and other previous discussed technologies could not support for the best delivery of mobile TV service to mobile handsets. DVB-H provides different mobility features such as time slicing for power saving and 4K mode in the modulator for enforcing immunity against Doppler effects while the receiver is in motion mode. These features provided by DVB-H and others are presented into more details in the following sections.

4.5.1 Time slicing

The main feature that makes DVB-H distinguishable from DVB-T is time slicing. This feature is a key factor of power-saving. It was added to adapt DVB-T stream to the mobile handset. This mechanism transmits data services in bursts which reduces the average power consumption of the receiver by 95% [3]. The data burst are then stored in the receiver memory and played back continuously during the time period between the bursts. This way the mobile users do not experience any interruption in the broadcasting.

In addition, while the transmitter is always on, providing a continuous transmission, the receiver operates only when the burst of the selected service is expected. Each burst then notifies the receiver when it should wake up for the next coming burst.

With DVB-T, the signals are transmitted as a continuous stream, where a number of channels are multiplexed together. The packets from the different channels then follow sequentially at a very high data rate. At such a high data rate the receiver needs to be active all the time to receive the packets continuously. By contrast, with DVB-H, the signal is divided into time sliced bursts and the IP encapsulator dedicates a full capacity of the multiplex to only one channel for a certain period of time [3]. Therefore, all packets for a certain channel arrive in bursts during that period and no other packets from other channels arrive during this period. This allows the receiver to be active only during that period of the selected channel and sleeps while waiting for the correct burst. This mechanism of switching on and off allows the receiver to save power. Figure 4.6 gives an overview of the time slicing in DVB-H.

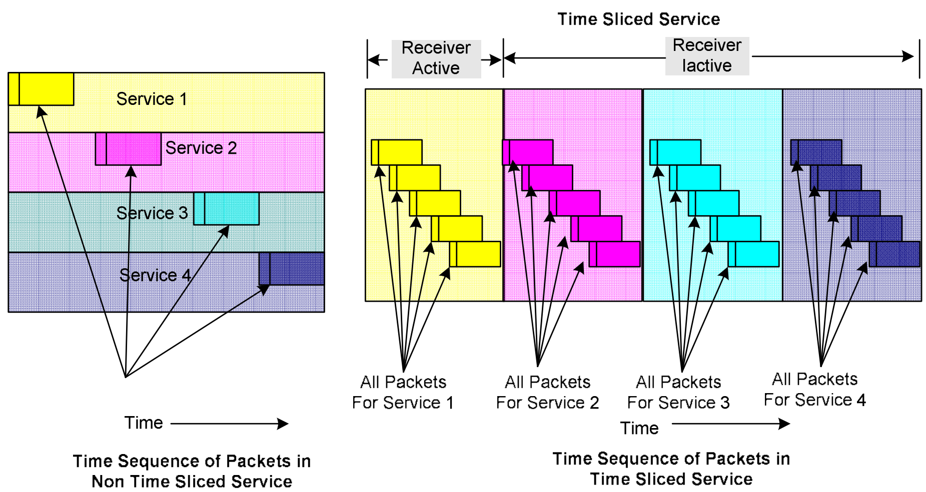

Figure 4.6 Overview of the Time Slicing in DVB-H [3]

For the purpose of synchronization, the receiver needs to wake up sometime before the arrival of the wanted burst. In practice, 200ms is the time needed for synchronization [21]. This mechanism allows the receiver to be off power for up to 90%[26] of the time. This, however, depends on the number of services that are multiplexed. The time-sliced and non-time-sliced services can share the same Multiplex as depicted in Figure 4.7.

[26] DVB-T MPEG-2 program can stream data as fast as 10 Mbits/sec, which is larger to what a mobile handset can reasonably process and display on a QVGA screen. In DVB-H, a bit stream less than 500 kbits/sec would be enough to provide good-quality video resolution on a handset. That means for the DVB-H receiver to receive 500 kbits/sec, the receiver is turned on only 500/10,000 = 5% of the total receive duty cycle, and hence a theoretical power saving is 95%. In practice the synchronization time of the receiver is also added which is then assumed that the total power consumption is around 90% [22].

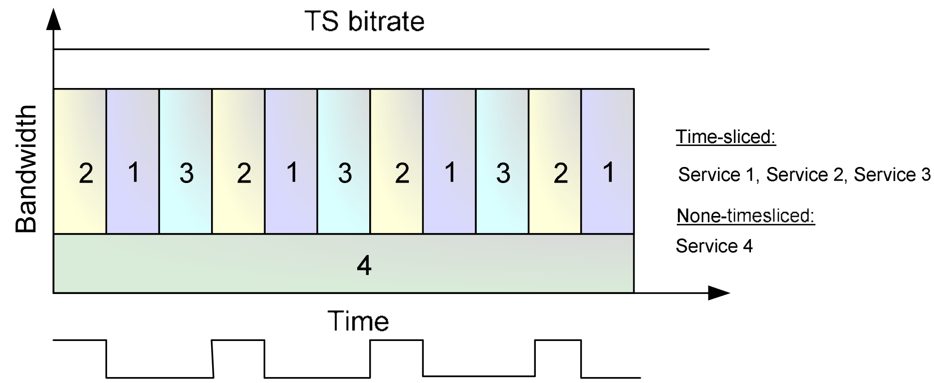

Figure 4.7 Time-sliced and Non-time-sliced services in common Multiplex [23]

4.5.2 Handover support

Another advantage of time slicing is that during inactive time (off-time between bursts) the receiver monitors the neighboring cells during this period to search for higher signal strength in the neighboring cells, while maintaining the current service to the mobile user. The receiver switches to another cell that provides the same service in case the signal strength of the latter is better than the current cell.

The process of checking the signal strength in the neighboring cells has no impact on the overall power saving because, although this mechanism requires the receiver to be powered during signal scanning, it requires only a fraction of the off-time between the bursts [15]. Note that while the *cell identifier* was optional in DVB-T, this is not the case in DVB-H as the cell identifier enables a faster signal scan and fast discovery of the neighboring cells where the selected service is available [15]. This mechanism helps to provide a seamless handover to the appropriate transmitter or repeater where the available signal strength is strong. Figure 4.8 below depicts an overview of the handover in DVB-H.

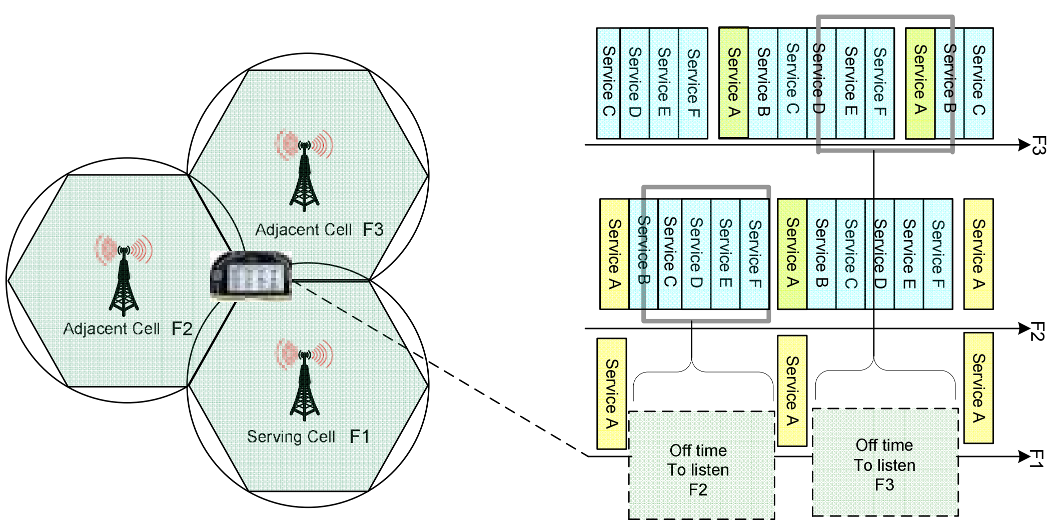

Figure 4.8 Overview of handover in DVB-H [23]

When the current signal strength in one cell is dropped below a certain threshold, the mobile receiver attempts to switch to another cell where the signal strength is higher[27]. In addition, if the receiver switches to a new cell, it automatically tunes into a new available frequency where the signal is carrying a similar service.

It is worth pointing out that in a Single Frequency Network (SFN), the handover is needed only when the mobile receiver switches to another network. This is because all the transmitters in an SFN form one single cell.

4.5.3 MPE-FEC

The audio and video content in DVB-H environment is transmitted using IP datacasting [3]. That means that the content is encapsulated with IP headers prior to transmission, in the same way the IP packets are transmitted over the Internet. However, the mobile environment is not as robust as the Internet and the signal is vulnerable and exposed to variations such as interference and a high level of man-made noise. As a result, the signal quality may degrade and causes erroneous data at the receiver.

Even though COFDM transmission provides immunity to such limitations (e.g. signal fading and multi-path transmission effects), additional means for data error correction have been added to cope with these effects. In order to ensure robustness and provide better quality service and reception in a mobile environment, Reed Solomon[28] FEC data protection has been added with DVB-H at the MPE layer [3]. This data protection is done using the forward error correction mechanism FEC and is carried out in the IP encapsulator at the data link layer. The IP encapsulator delivers IP datagrams in MPE sections, whether MPE-FEC is used or not [3]. This is an advantage because it will ensure backwards compatibility reception with the receivers that do not support the MPE-FEC feature.

Furthermore, the MPE-FEC is intended to reduce S/N, improve the Doppler performance in mobile channels and the tolerance to impulse interference [24]. It allows further correction on the imperfectly received IP datagrams. This result proves that a significant resilience can be achieved in a mobile environment. Moreover, adding this extra feature to the transmitter will have no impact on the receivers, which do not support MPE-FEC, because they can simply ignore FEC sections [15]. The detail information about FEC section is found in the appendix D.

It is worth pointing out that while time-slicing is mandatory to increase the battery usage duration of the mobile handset, MPE-FEC is optional. The network operators should be careful in using this feature, as it requires extra power consumption both for the transmitter and receiver handset. Moreover, while MPE-FEC provides extra performance in a mobile environment, it lowers throughput by around 25% due to the parity overhead [15].

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[27] This mechanism can be achieved by different means, such as evaluating the bit error rate (BER).

[28] Reed-Solomon is an error correcting code which can correct up to 8 bytes error out of a 204-byte word [29]

4.5.4 4K mode

The 4K carrier mode has been added in the DVB-H standard to provide network optimization [15]. The 4K mode provides immunity to signal variation and interference. It also provides additional flexibility for network planning. The 4K mode has been introduced as a trade-off between the two already available parameters in DVB-T: the 2k and 8k carrier modes [15]. 2k offers short transmission cell-size and maximum receiving speed[29], while 8K offers large cell-size and low receiving speeds.

In the 4K mode, mobility is increased by a factor of two compared to the 8K mode and the SFN size is two times larger compared to the 2K mode. Moreover, the 4K mode may only be used in DVB-H networks as DVB-T does not support this mode. Figure 4.9 below depicts the coverage area and the maximum transmission distance that can be achieved by the transmitter using different carrier modes [25]. Note that the distance can vary depending on the transmitted power and the selected OFDM mode.

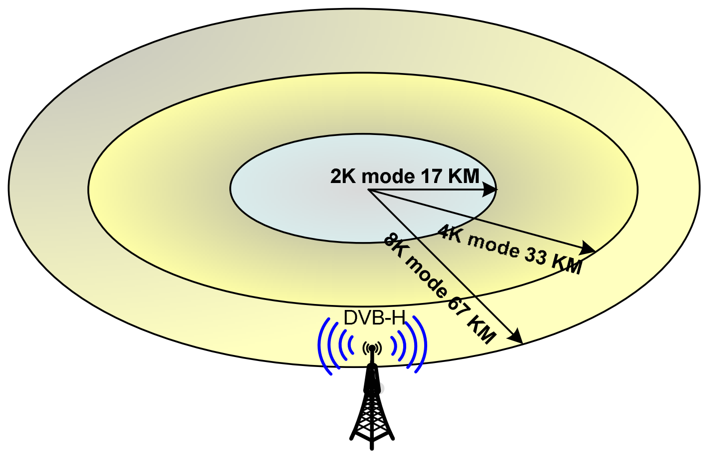

Figure 4.9 Maximum transmitter Distance

4.5.5 In-depth Interleaving

DVB-H makes use of the available memory of the 8K symbol interleaver implemented in the receiver to offer an in-depth[30] interleaver to be used with the 2K and 4K transmission modes [24]. When the option of in-depth interleaver is selected for the 2K transmission mode, the interleaving is extended over two OFDM symbols, whereas if the 4k is selected, the interleaving is extended over four 2K OFDM symbols[31]. This approach results in tolerance to impulse noise interference of 2k and 4k modes up to the level that can be attained with the 8K mode. It aims also to improve the robustness and performance in a mobile environment. Figure 4.10 below depicts the various symbol interleaving mode schemes.

[29] The speed at which the signal can be demodulated

[30] The term in-depth interleaving refers to a process where all the available memory is used. Note that if a symbol interleaver that is specific to individual mode is used the process is then called native-interleaving [25].

[31] In other words, this means that the impulsive noise power is spread over 2 and 4 symbols for 4k and 2k respectively.

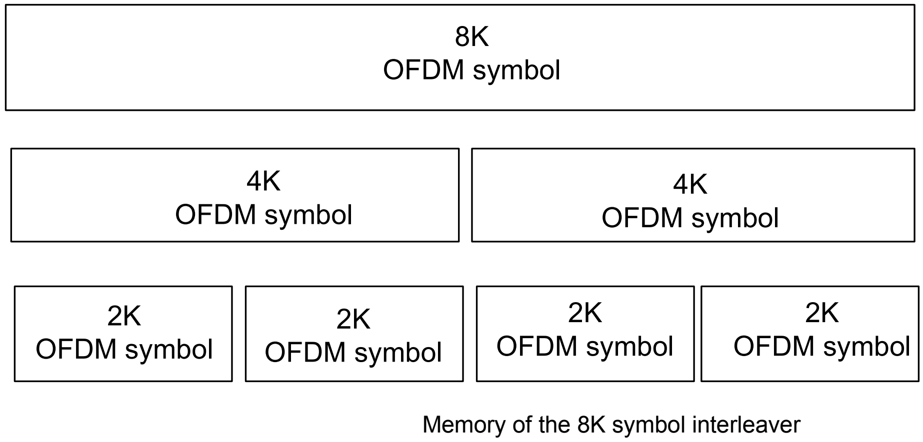

Figure 4.10 DVB-H in-depth interleaving of OFDM symbols [24]

Although the in-depth interleaving results in tolerance to impulse noise interference, when used in SFN, an additional delay of 1 OFDM symbol is introduced for the 4k mode. In 2k mode, an additional delay of 3 OFDM symbols is introduced [15]. Therefore it is necessary for the network designers to take this into account and should find a way to compensate for the additional delay.

4.5.6 DVB-H signaling

We have mentioned earlier that the time slicing DVB-H and non-time slicing DVB-T services can be placed in the same multiplex. Therefore, in order to differentiate between the two services, DVB-H needs some robust signaling at the physical layer to indicate whether the received signal is DVB-H and whether MPE-FEC is used or not. The signaling bits are used for this purpose in the DVB-T stream. These signaling bits can carry information about DVB-T as well as DVB-H.

The signaling frame in DVB-T consists of 68 TPS bits, 23 bits are used for DVB-T parameters to carry information about transmission mode and cell-identifier (S25 to S47) [26]. The cell-identifier carried out in the TPS bits is used to support faster signal scan and frequency handover on mobile receivers. The handover mechanism is further detailed in section 4.5.2.

Amongst other signaling bits, the bits s48 and s49 are used to indicate whether the time slicing or MPE-FEC is used or not. The table below depicts the different combinations of (s48, s49) and their corresponding DVB-H signaling description.

s48	**s49**	**DVB-H signaling**
0	X	Time Slicing not used
1	X	Time Slicing used = DVB-H *
X	0	MPE-FEC not used
X	1	MPE-FEC used *

* At least in one elementary stream

In addition, the rest of the TPS bits can carry other information to for instance indicate whether the signal is DVB-H and whether 4K or 8K mode is used.

4.5.7 IP Datacast

As it has been mentioned earlier, the DVB-H technology is based on the IP Data casting technology. The IP data cast (IPDC) broadens the type of digital content that can be delivered or broadcasted to mobile handheld receivers. With IPDC, all digital content is transmitted in form of IP packets [19]. Figure 4.11 is an overview of the DVB-H IP data cast.

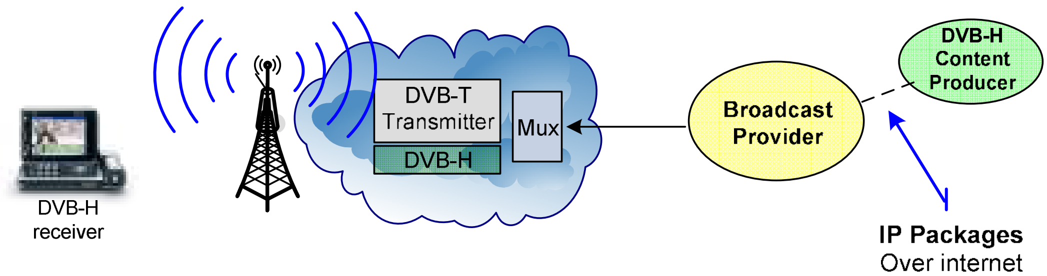

Figure 4.11 Overview of DVB-H IP Datacast

The nature of IP platform is suitable to carry any type of content. That makes IPDC suitable for carrying different contents such as audio and video streams, music files, games etc. The main advantage in using IP as an underlying technology for DVB-H is that the data content can be handled by currently existing devices and protocols used on the Internet. The other advantage is that IPDC allows the transmission of the content to be protected from illegal viewing [19]. More details about security and digital right management can be found in the appendix C.

5. TECHNICAL USAGE SCENARIOS

We have seen in the previous section that DVB-H has been designed to use the existing DVB-T network infrastructure. In this section we will see the possible network configurations that can be implemented for DVB-H. Three network configurations for DVB-H implementation are described as follow.

5.1 DVB-H SHARED NETWORK

DVB-H can share the DVB-T infrastructure by sharing the same DVB-T multiplex, see Figure 5.1 below. In this configuration, mobile TV channels coming from the IP encapsulator share the same DVB-T multiplex with other terrestrial TV channels [3]. The TV channels intended for stationary TV sets can be coded in MPEG-2, while TV channels intended for mobile handsets can be coded in for instance MPEG-4. The combined multiplex channels are then sent into a single transport stream which will then be transmitted after modulation.

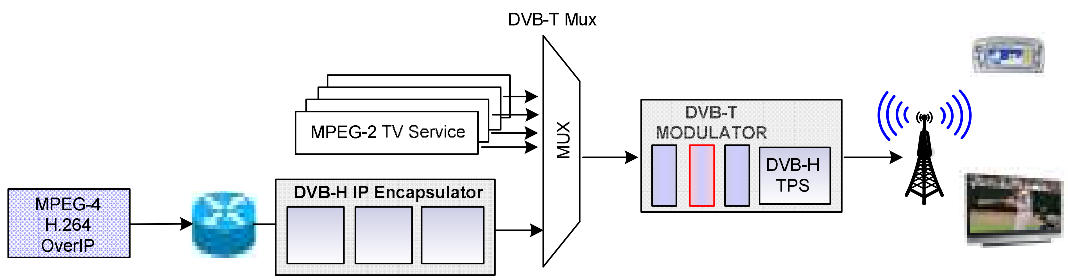

Figure 5.1 DVB-H on a Shared Multiplex

The DVB-H key component in this network scenario is the IP-encapsulator. It generates MPE sections from the incoming IP datagrams as well as MPE-FEC sections if used. It also implements the extra feature of time slicing. The time slicing and MPE-FEC features are detailed in section 4.5.

Although this network scenario allows reusing[32] the existing DVB-T infrastructure, it has a drawback that the transmission mode is unique [27]. This is because the DVB-T receivers do not support the 4k mode discussed in section 4.5.4. As a result, the DVB-H service availability and quality of service will be compromised especially for indoor and moving at high speed mobile handsets.

Additionally, as mentioned earlier the DVB-T transmission is meant for stationary TV sets with a large mounted antenna on the rooftops which can be directed toward the transmitter. By contrast, the DVB-H signal needs to reach the mobile handsets with small build in antenna in an unstable mobile environment. Another requirement is that the mobile handsets should also be reached inside the buildings. Due to these factors the required transmitted power in DVB-H should be much higher than in DVB-T [3]. The latter also depends on the antenna height. According to Amitabh Kumar [3] if the EIRP from an antenna (120m) height in a range of up to 5km is 46dBm, then an antenna of 25m would require around 79dBm of EIRP in the same range.

[32] Re-using DVB-T infrastructure allows reducing the overall cost of DVB-H network implementation. The DVB-H network investment is discussed into more detail in section 7.

5.2 DVB-H HIERARCHICAL NETWORK

DVB-H can also be shared with DVB-T by hierarchy, see Figure 5.2 below. Unlike the DVB-H shared network where the DVB-T and DVB-H streams are combined in a single transport stream, in a hierarchical network the DVB-H and DVB-T streams are transported separately. The modulation is hierarchical with the two streams, where the DVB-T stream is modulated as low priority, and the DVB-H stream is modulated as high priority [3].

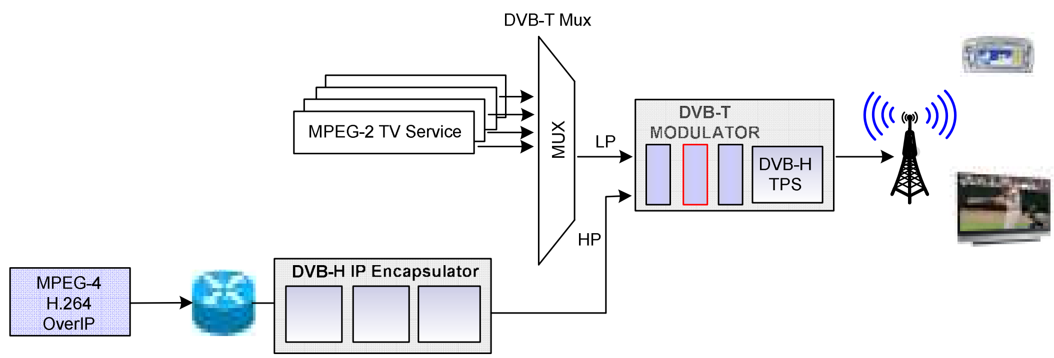

Figure 5.2 DVB-H using Hierarchy

The advantage of this network scenario over the multiplexing scenario is that different modulation parameters can be set for fixed DVB-T as well as for DVB-H reception. This option will lead to more optimum bandwidth usage. The modulation is more robust in case of high priority which can use different modulation schemes, such as QPSK. The latter ensure excellent performance in a mobile environment. Whereas in low priority, the modulation scheme would be 64 QAM to ensure higher bit rate for stationary reception [15]. The disadvantage of this network scenario however, is that the amount of bandwidth that is reserved for DVB-H services should be fixed, which decreases network flexibility. Also and similar to DVB-H shared network the optional 4K mode cannot be used in this network configuration, simply because DVB-T receivers do not support this mode.

Additionally, when planning DVB-H service for mobile outdoor and portable indoor reception as high priority stream, the low priority stream would be transmitted *almost for free* [15]. The reason is due to the fact that this network planning would also be applicable for DVB-T. Similar to DVB-H shared network, introducing DVB-H service hierarchically into existing DVB-T network will reduce the required network resources and hence low cost implementation of DVB-H network.

5.3 DVB-H DEDICATED NETWORK

DVB-H can also be built from scratch using dedicated network, see Figure 5.3 below. In this network configuration, the COFDM carrier is used exclusively for DVB-H transmission [3]. This network scenario can be used by operators who have not yet implemented a DVB-T network.

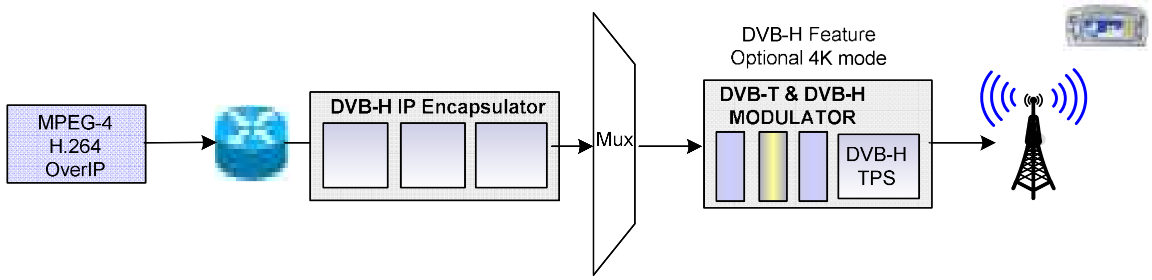

Figure 5.3 Dedicated DVB-H Network

The advantage of dedicated DVB-H network over the previously network scenarios is that the spectrum assigned to DVB-H will have no impact on the available spectrum for DVB-T. Whereas in a DVB-H shared and hierarchical networks, the spectrum assigned for DVB-H services will reduce the available spectrum for DVB-T

Additionally, unlike the DVB-H shared and hierarchical networks, the dedicated DVB-H network is the most suitable as it allows flexibility. This is because it can be optimized for any desired capacity and coverage without any constraints imposed by DVB-T. Also the dedicated network can take advantage of using the 4K mode and in-depth interleaving which gives extra flexibility for optimizing the network performance. According to Aurelian Bria, David Gómez-Barquero research [28], with the same transmission power, the coverage area is larger in the dedicated DVB-H network than in a shared network (see figure E.2 and E.3 in the appendix E). The main drawback, however, is that from an economic point of view, this network scenario is much more expensive in terms of capital expenditure than the previously discussed network architectures. This is because it needs new core network equipment as well as a separate frequency channel [27].

6. NETWORK PLANNING

We have seen in the previous section the possible network configurations for DVB-H implementation. In this section we will present the technical challenges and the regulatory aspects for implementing DVB-H network.

6.1 TECHNICAL CHALLENGES

This section will discuss some of the technical challenges of mobile TV broadcasting. In particular it will focus on the coverage and mobility issues.

6.1.1 Coverage

When implementing a DVB-H network, it is very important to think about the coverage area - the larger the coverage area the larger the number of users[33]. However, since the success or failure for the DVB-H is mainly determined by the revenue of user subscriptions, extending the coverage area would be beneficial and will consequently increase the revenue.

Many measures should be taken to increase the coverage area of DVB-H broadcasting, such as the direction and location of the transmitters [29]. The direction of the main transmitter radiation power should be adjusted to achieve adequate field strength for reception of services within the service area of the transmitter. The location of the transmitter (main-station), on the other hand, should also be close to centers of population to ensure coverage of large populations. This also means that more revenue will be generated from large subscriptions.

In order to achieve the necessary field strength and ensure coverage for indoor reception, a number of transmitters and gap fillers[34] are required [15]. The latter are necessary to fill in the gaps where the coverage may not be available such as inside the buildings and in tunnels etc. The number of gap filters, however, is proportionally associated with the power of the main transmitter as well as the height of the tower. The Effective Radiated Power (ERP) transmitted and the height of the transmitters are two of the main factors affecting the coverage [30].

Theoretically, high tower and high power will reduce the number of gap fillers for a given area. The higher the transmitter tower the larger is the coverage area that can be served. Additionally, the more power emitted the better signal quality can be achieved. Therefore, the number of gap fillers reduces with the increase of either the power transmitted or the tower height.

Furthermore, the amount of power needed for a DVB-H network depends on the terrain and area size. Based on his research, Tuukka Autio [31] wrote that in the optimal network configuration, the minimum power for the large broadcast towers should be 10 kW while for medium sized sites it should be 4 kW.

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[33] Although this might not always be the case, in this thesis we assume that the number of subscriptions increases with the increase of the target population size.

[34] Gap fillers are low power co-channel mini-transmitters with high gain antennas for receiving the signals from the main station, boost and retransmit the signal to fill in the coverage gaps.

6.1.2 Mobility

Delivering mobile TV services to mobile receivers is a challenging problem. The mobile communication system can be subject to data loss due to different phenomena, such as Doppler effects and interference. Therefore, a reliable data transmission should be guaranteed even in the presence of these phenomena. This however can be achieved by service maintainability allowing uninterrupted access to network services and service consistency when the user is moving.

The maintainability of the service is provided by the time slicing feature. For more details about time slicing please refer to section 4.5.1. This new mechanism which has been added to DVB-T allows user transition from one cell to another without interrupting the current service. On the other hand, the service consistency, which implies robust reception when the user is moving, can be achieved by a careful selection of modulation techniques and additional data correction [3]. As we have seen in section 4.5.3, the data loss improvement of reliability can be recovered using forward error correction (FEC). Although this additional data correction may impose additional resource usage and reduce the data rate due to additional overheads, this is still justified because it ensures maximum performance and data reliability [14].

The mobile environment has a great impact on the DVB-H network performance. Unfortunately, when the environmental conditions are favorable[35], DVB-H broadcast suffers loss of signal quality especially for indoor reception [29]. Besides the Doppler effect previously discussed, the loss of signal quality can be caused by some other phenomena. This includes signal fading due to climatic changes, interference, building penetration loss, signal reflected from distant and moving objects, ect. These all contribute to multiple path transmission or unwanted noise at the receiver.

Because of the characteristics of the mobile environment, the radio conditions also changes depending on the location of the mobile user. Figure 6.1 illustrates an example of the environmental impact transmission effects on the mobile reception.

[35] For instance, according to Seamus O'Leary [29] significant interference can be expected at times of exceptional propagation, such as high atmospheric pressure.

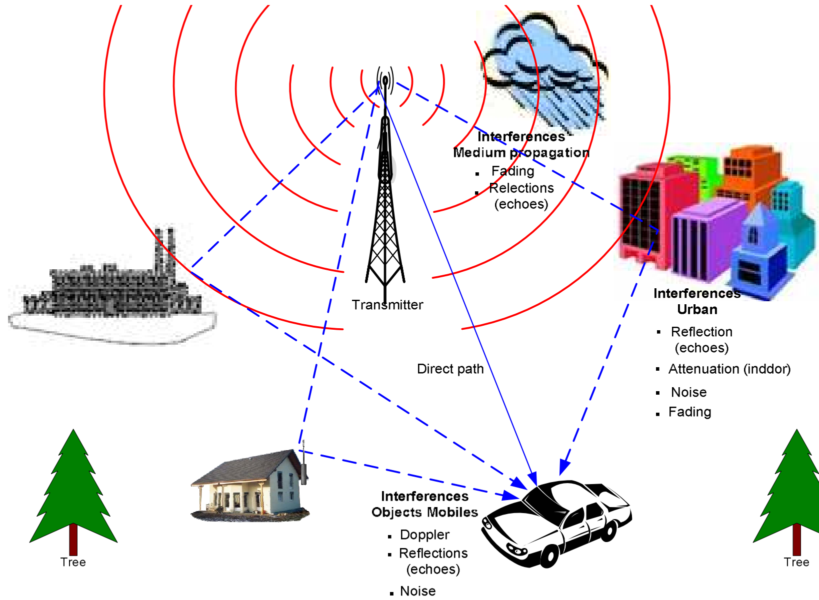

Figure 6.1 Multi-path Channel and Mobile Reception[36]

From the figure above it can be seen that multipath transmission is a major problem for mobile receivers, because the position of the latter can change very rapidly over time [32]. The problem arises due to the difference in arrival time of two signals that carry the same information, which may cause interference between the reflected and direct signal.

The interference can also be caused by the transmitters' physical separation distance in the SFN network [29]. The signals from these transmitters may be delayed in relative time to each other. If this distance is large enough, it can create delay, which exceeds the system guard interval duration. The delayed signal will then act as noise and cause interference at the receiver [29]. The multipath transmission may also cause long delay spreads depending on the distance separation between the transmitters [29]. Figure 6.2 illustrates an example of the delay spread[37] due to two transmitters.

[36] The idea has been inspired from [33]

[3737] Delay spread is the time difference between two arrival signals at the receiver [David Tse from university of California]. The delay spread can lead to inter-symbol interference due to multipath signal overlapping symbols.

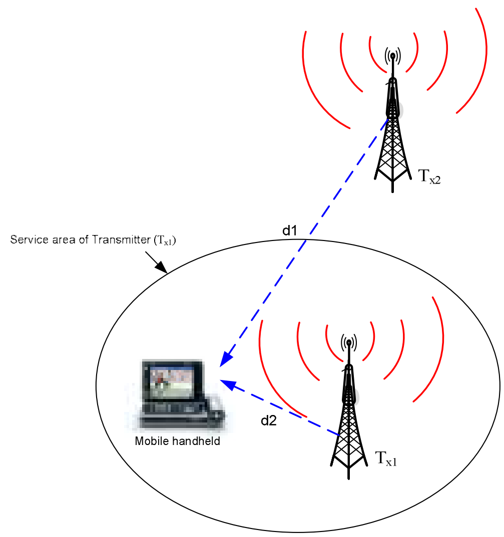

Figure 6.2 Delay spread due to two transmitters [29]

In the presence of delay spread, the network can be adjusted so that the signals arriving simultaneously at the mobile receiver will be added constructively without interference [15]. This can be achieved by a careful selection of the system operating mode. In that case, the 4k mode would be suitable if a dedicated DVB-H network is used. The detail information about 4K modes is found in section 4.5.4. Adjusting the guard interval duration would also help to cope with the network transmission delays. Table 6.1 shows the different guard interval durations (maximum delay tolerated in SFN) for different modes.

Guard interval	8k mode	4k mode	2k mode
1/4	224 μs	112 μs	56 μs
1/8	112 μs	56 μs	28 μs
1/16	56 μs	28 μs	14 μs
1/32	28 μs	14 μs	7 μs

Table 6.1 Guard interval duration for all modes [15]

When planning the DVB-H network a special attention must be given to properly locate and space-out the transmitters to avoid signal interference. The latter can be reduced by adjusting the duration of the guard interval. Table 6.2 illustrates the maximum transmitter distance separation allowed and the maximum delay in a Single Frequency Network (SFN)[38] in combination with the guard interval and operating modes.

[38] Note that all the transmitters in the SFN network use the same broadcast channel for the same TV mobile service. This also requires careful design of the network as the transmitters in SFN have to be synchronized so that they transmit the same bit information at the same time and on the same channel [3]

	Mode		
OFDM parameter	**2K**	**4K**	**8K**
Overall number of carriers / FFT size	2048	4096	8192
Number of modulated carriers	1705	3409	6817
Number of data carriers	1512	3024	6048
Useful OFDM symbol duration (µ)	224	448	896
Guard interval duration (µs)	7, 14, 28, 56	14, 28, 56, 112	28, 56, 112, 224
Carrier spacing (kHz)	4.464	2.232	1.116
Maximum transmitter distance (km)	17	33	67

Table 6.2 Parameters of the possible DVB-H OFDM transmission modes (8MHz chs) [25]

The OFDM mode can be selected based on the desired cell size and maximum allowable speed of mobile users. As can be seen from the table above, the guard interval of $1/4$ with maximum duration $224\,\mu s$ will allow a separation distance between two transmitters to be around $67\,km$ in 8K mode. This means that if the transmitter separation exceeds that distance, interference may be expected. What also can be noted from the table is that the guard interval duration in 4k mode is increased by 2 times factor than in 2k and half that of 8k. This is clear evidence that the 4K mode offers larger distance separation of the transmitters than 2k. Moreover, it provides around 2 times better Doppler performance than the 8k mode.

Furthermore, in-depth interleaving is also another means to enforce transmission reliability in a mobile environment. This mechanism spreads out symbol errors that occur in bursts. Interleaving is a powerful method to improve the error capabilities in a wireless system that is subject to fading. The in-depth interleaving mechanism is detailed in section 4.5.5.

6.2 ADVB-H REGULATORY ASPECTS

"*The availability of spectrum is key to the roll-out of mobile TV and radio*" said World DMB president, Quentin Howard [Informa, April 2007].

The analogue television networks are currently being phased-out and progressively replaced by the digital television network. The Danish Government expects the analogue TV to be phased-out by the end of October 2009 which has been set as an official date for analogue TV switch off in Denmark[39].

In connection with closing analogue TV services, the frequency range is being released which can be used for long range purposes. This includes, High-resolution digital TV broadcast (HDTV), mobile telephony, digital radio as well as mobile TV.

The most important regulatory aspect influencing the implementation and commercialization of DVB-H is the availability and use of the frequency spectrum [34]. It is the common resource which requires the broadcasters to acquire a license for launching mobile TV services.

[39]Source: http://www.dvb.org/about_dvb/dvb_worldwide/denmark/index.xml

The DVB-H technology as all the wireless technologies depends on the use of the spectrum for the delivery of mobile TV services to mobile users [3]. As it has been mentioned earlier in section 4, DVB-H was designed to use the existing DVB-T networks so that DVB-H services can also be carried through it and use the same spectrum as DVB-T. The DVB-H designers have stated their preferred spectrum in the broadcast UHF Band IV (470-650MHZ) [5]. It is supposed to be the optimal frequency range for mobile TV services[40].

UHF bands offer excellent[41] building penetration which means large cell size. Operation in the L-band[42] (1.67GHz) and –band S (2.2GHz) are also possible [35]. More importantly, the UHF Channels 21 to 49 (from 471.25 to around 698MHz) are preferable for return channel compatibility with GSM [36]. Note that if DVB-H is to be supported by mobile handsets operating at GSM 900 MHz, the useful frequency range should be below 750 MHz [11]. This is very important as to prevent blocking the DVB-H low power mobile reception by high power GSM transmissions.

In fact, the use of spectrum is country specific. Different frequency bands have also been assigned for DVB-H broadcast use. For instance, in the United States the company Modeo laid out a new platform specifically designed for the DVB-H TV standard using L-band at 1670 MHz for Mobile TV services [37]. HiWire, the largest owner of 700MHz spectrum in the United States, is also launching DVB-H services using this spectrum slot [38].

[40] This is due to the fact that the frequency is low enough to provide long distance transmission and high enough to avoid interference caused by man-made noise [29]

[41] According Seamus O'Leary [29] "UHF bands are more attractive, having better propagation characteristics "

[42] L-band cannot be used in Europe because it has already been assigned to DAB. Another fact is that the L-band signal diffraction is significantly less than in UHF, which means that the signals being transmitted on UHF would have a better building penetration than L-band. Despite these facts the L-band is said to provide a safer environment than UHF does. This is because the human body is less resonant at L-band wavelengths [30].

7. ANALYSIS

The growing popularity of mobile handsets, such as cell phones and PDAs, has been driven by an increasing demand for a variety of mobile services. This includes multimedia services in general and TV services in particular. This however implies the need of a viable and economical technology that will meet the growing demand of such services. In this section, an analysis of the economics of cellular unicast and DVB-H broadcast technologies will be discussed to demonstrate the advantage of broadcast over the unicast technology[43]. This is followed by describing a possible business model that makes use of both unicast and broadcast technologies to make money. Paying willingness is also given to discuss the generated revenue from mobile TV subscription fees. Two case studies will then be presented to estimate and discuss the implementation cost of DVB-H network in Denmark. Finally, market forecasts for mobile TV will be discussed.

7.1 THE ECONOMICS OF UNICAST AND BROADCAST TECHNOLOGIES

We have seen in section 2.3 that nowadays mobile TV is offered by cellular network (unicast in nature) operators. With the high capacity available in cellular networks, such as 3G, one would think that there is no need for new technology to deliver mobile TV to handsets receivers. However, in order to illustrate the advantages of DVB-H broadcast network over unicast cellular networks, this section will present the economics of unicast and broadcast technologies to prove that, from an economical point of view, the DVB-H broadcasting technology would be the most practical and sustainable technological solution for mobile operators.

For the purpose of this comparative analysis two different tables will be used: Table 7.1 and Table 7.2. The first table (Table 7.1) shows the common data rates for mobile TV. These are affected by the frame rate as well as by other factors such as screen size, screen resolution and compression ratio [39]. Those parameters have a great impact on the video quality which is compromised with higher compression rate and lower frame rate. In the following analysis 128 Kbps and 384 Kbps will be used as low and high data rate, respectively. The data rate 768 Kbps, could also have been used as higher data rate but that is not feasible because it would significantly limit the number of transmitted channels [39].

	Data Rate	Frames per Second (fps)
Class A	128 Kbps	10-12 fps
Class B - Low	256 Kbps	15-20 fps
Class B - High	384 Kbps	20-25 fps
Class C	768 Kbps	30 fps

Table 7.1 Common data rates for mobile TV [39]

The second table (Table 7.2) depicts the different services along with the bandwidth required for each service. Because the economics of a cellular network is usually measured by the generated average revenue per Megabit, the average revenue from each service is included. The total capacity usage of services offered by the cellular operators is also included. Note that this table is depicted under the assumption that the

[43] The analysis has been inspired by the research conducted by Yoram Solomon "The Economics of Mobile Broadcast TV" [39].

average revenue is generated from the customers' subscriptions fees with no additional costs associated with the video content or spectrum acquisition.

Service	Bandwidth	Average Revenue	Capacity Usage in Mb	Average Revenue/Mb[44]
SMS message		0.38 DKK	0.0002	1900 DKK
MMS Photo		1.1 DKK	0.0098	112 DKK
2 minute voice call	12 Kbps	0.38 DKK	1.4400	0.26 DKK
2 minute low-resolution video	128 Kbps	5.42 DKK	15.3600	0.35 DKK
6 minute low-resolution video	128 Kbps	5.42 DKK	46.0800	0.11 DKK
6 minute high-resolution video	384 Kbps	5.42 DKK	138.2400	0.04 DKK
30 minute high-resolution video	384 Kbps	10.41 DKK	691.2000	0.02 DKK

Table 7.2 Revenue and Bandwidth of over-the-air services[45]

7.1.1 The Economics of Unicast video

As it has been mentioned earlier in section 2.3, mobile TV in Denmark is being offered by cellular operators using the high capacity available in the existing 3G networks. From the table above, it can be seen that a two minute voice call at around 12 Kbps would cost 0.38 DKK and use 1.44 Mb of the available capacity. Whereas watching a 30 minute high-resolution video at 384 Kpbs would cost 10.41 DKK and use 691.2Mb.

If we assume that the cost to the cellular network operator is 0.11[46] DKK per Megabit, then in order for the network operators to make profit, the revenue should exceed 0.11 DKK. Clearly, SMS and MSM are profitable services with 1,900 and 112 DKK per Megabit, respectively. Voice calls are not as profitable as SMS and MMS services but still also profitable with 0.26 DKK.

While the 6 min low-resolution video program of 128Kbps hits right at the break even point at 0.11 DKK per Megabit, the 6 min or 30 min high-resolution video program of 128Kbps are far from being profitable with only 0.04 and 0.02 DKK revenue per Megabit.

As can be seen from the above results, the network operator would have two options to make video services profitable. The operator either needs to increase the price of the service by offering high-resolution quality or go for lower-resolution by offering shorter programs

Now if we assume that the operator chooses to increase the price of the mobile TV programming above 0.11 DKK per Megabit, then he should charge the mobile user more than $(5.42\times 0.11)/0.04 \approx 15$ DKK for six minutes and $(10.41\times 0.11)/0.04 \approx 29$ DKK for a 30-minute high resolution TV program. It is highly unlikely that mobile TV consumers will be willing to pay such an amount for that kind of service. Therefore, the option of increasing the price for high-resolution TV program would not be practical at all.

[44] Average revenue/Mb =(Average revenue / capacity usage in Mb)
[45] The structure of the table has been taken from [39] and modified to serve the purpose of this analysis. The main changes include converting the average revue from Dollar to Danish krone (rate = 5.479).
[46] According to Yoram Solomon [39] "the cost to the operator of the cellular network operation (without amortizing the spectrum acquisition costs) is close to 2¢ per Megabit.". If we convert this amount to Danish krone, the amount would be around 0.11 DKK (currency rate = 5.479).

Choosing the alternative option, if the mobile operator reduces the quality of TV programs to 128Kbps with for instance a 2 minute maximum, the revenue would be 0.26 DK which still keeps the service profitable. However, this second option would not be practical as well, because it is unlikely that mobile users would pay 5.42 DKK to watch such a short and low quality video program.

7.1.2 The Economic of Mobile TV Using 3G Platform

If we assume the capacity of $3G$ BTS is around $2.5\,Mbps$ [39], then the network can serve $3600 \times 2.5Mbps = 9Gbs$ during one hour. Now if we assume that an average voice call of two minutes would use 1.44 Mbs of the capacity then the network can serve up to $9Gb/1.44Mb = 6250$ subscribers or calls.

To better understand the economy of Mobile TV using the 3G network, we assume the following scenarios:

Scenario 1: In this scenario, we assume a 2 minute low quality video stream with 5% of the subscribers watching TV. That means $6250 \times 5\% \approx 312$ subscribers will watch TV in one hour. Since they will be watching 2 minute clips at 128 $kbps$, they will use $128 \times 2 \times 60 = 15.36$ MB of the total network capacity. In one hour, the total capacity consumed will be $312 \times 15.36Mb = 4.8Gb$ which means that only $4.2Gb$ will remain for voice conversations.

Scenario 2: If we take the same example as in scenario 1, but this time the length of the video clip is 6 minutes. In this case, the users will consume $46.08Mb$ during a 6 minute period. Over one hour, 5% of the subscribers will consume $312 \times 46.08Mb = 14.4Gb$, which is even more than the total network capacity. This also means that with only 62%[47] out of 315 subscribers watching TV, the entire network is clogged up and none of the 6250 users of the network will even be able to place a call.

Scenario 3: Assuming a good quality video of 384 $kbps$ and a video length of 6 minutes, the consumption of a single clip will be $138.24Mb$. In one hour, 312 subscribers will consume $312 \times 138.24Mb = 43.2Gb$. This, however, is far from what the network can handle and in fact in this case the network would choke with only 21% [48]of the 312 subscribers watching TV, thus preventing all 6250 users from placing calls.

Scenario 4: Assuming now a low-quality video of 128 Kbps and a video length of 20 minutes. In this case the users will consume $154 \times 312\,Mb = 48.05\,Gb$, which means that only 18%[49] of the 312 subscribers will be able to choke the network for all the users by watching TV.

From the scenarios above, it can be concluded that delivering good quality video clips of more than two minutes in length over 3G networks, would result in preventing the network from providing voice calls. Even delivering low quality video to only 5% of

[47] In fact (14.4 - 9)/14.4 ≈ 38% out of 312 will not even be able to watch TV.
[48] It also mean that (43.2 - 9)/ 43.2 ≈ 79% out of 312 will not even be able to watch TV
[49] That means also that (48.05 - 9)/48.05 ≈ 82% out of 312 will not be able to watch TV.

the subscribers would prevent the network from providing voice services of more than 50% (see *scenario 1*).

Scenario 5: Now assuming that the mobile consumer will be watching TV on his mobile handset 20 minutes[50] a day on average. That means the consumer will be watching 600 minutes a month. If we assume a low-resolution rate of 128 $kbps$, the total consumption in terms of bandwidth will be $600 \times 60 \times 128 \approx 4.7\,Gb$ a month. At the break even point, the consumer would pay $4.7 \times 1000 \times 0.11 = 517\ DKK$ a month. It is unlikely that there will be a large demand for the service at this cost.

Scenario 6: If we assume now that the consumer will be watching 20 minutes of video clips on his mobile at a high resolution rate of $384\,Kbps$, the consumer would pay $384 \times 600 \times 60 \times 0.11/1000 = 1521\ DKK$ a month, which is far from realistic.

7.1.3 The Economics of Broadcasting Mobile TV

According to Yoram Solomon [39] there are three cost elements to compare the economic of broadcast and unicast technologies with respect to mobile TV. These elements are presented as follow.

1- Fixed cost of the network infrastructure and spectrum acquisition
2- Variable cost of the network infrastructure and spectrum acquisition
3- Variable cost of the content

In both unicast and broadcast networks, the cell-site tower is considered as a fixed cost. However, the spectrum and cell-site is fixed for broadcast but variable in unicast. The reason is due to the fact that the capacity and spectrum in unicast topology depends on the number of subscribers. If for instance the existing unicast network can serve 5% of the total subscribers for video streaming, handling extra subscribers will require extra capacity if the current quality of the service shall remain uncompromised. This however would not be possible, unless the existing network is upgraded to new technology that can offer more capacity to accommodate the growing number of subscriptions. This is entirely different in broadcast networks where the capacity and spectrum are independent of the number of consumers. Figure 7.1 below depicts the difference between unicast and broadcast technologies.

[50] As it has been stated in the introduction section, the results from surveys show that users are likely to watch mobile TV for an average of 20 minutes per day [2].

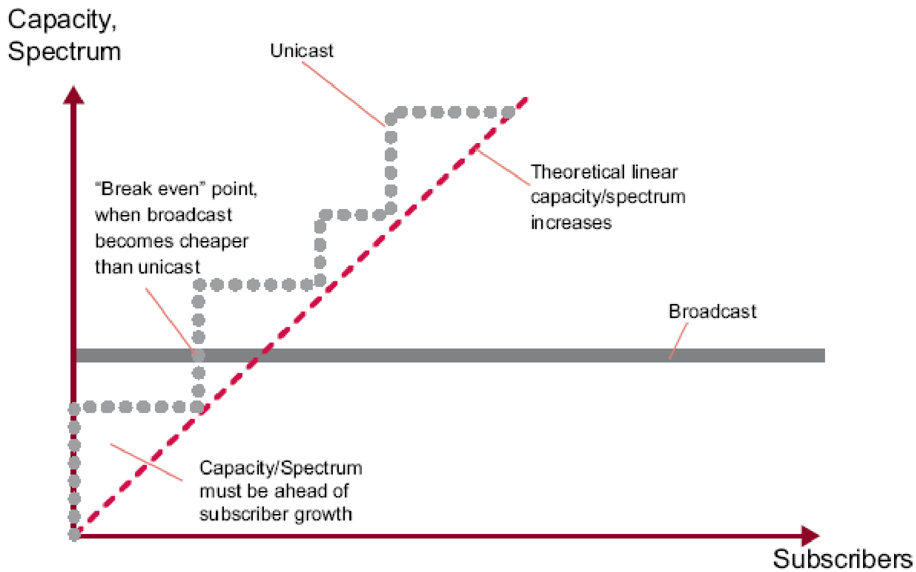

Figure 7.1 Capacity/Spectrum vs. Subscribers, Unicast and Broadcast [39]

From the figure above, it can be seen that the required capacity in unicast network increases with the number of subscribers. The required capacity in the unicast networks, such as 3G, increases proportionally to the number of users accessing the network. This makes these networks not scalable. Although these networks can be upgraded to the new technologies such as HSDPA or MBMS, the capacity of these networks will remain limited [25]. By contrast, the broadcast capacity remains fixed no matter how large is the number of subscribers. It can be concluded from the figure that the cost of unicast network will increase as the number of subscribers increases, but the broadcast network cost will always remain fixed.

The last element which is the cost of the content is the only one that is variable for both technologies. The operators need to pay content providers for the content being consumed by the subscribers.

From the above discussion, it is obvious that because there is no limitation in terms of the number of mobile users accommodated by the network, DVB-H is considered a highly cost effective technology to reach large audiences, far better than unicast mobile TV. However, the two networks as we will see in the next section complement each other. DVB-H enables serving large numbers of users simultaneously without compromising the network capacity, while the cellular networks can be used for interactivity.

7.2 DVB-H BUSINESS MODEL

It has been shown in section 3 that the DVB-H networks have an advantage over the existing technologies for mobile TV delivery on the market. The question now is whether there is any viable business model for the operators to uphold long term profitability of their DVB-H services?

In a mobile environment, the strength of broadcast networks and cellular networks can be combined. When combing the two networks, the existing services can be offered more cost-efficiently, and new types of services are possible as well. This way, the cellular mobile networks and DVB-H could be seen as complementary – where the broadcasters and cellular network operators must co-operate to build the market and generate revenues. The DVB-H network can provide content delivery to large number of users, while the cellular network permits interactivity such as SMS voting, purchasing and billing. Figure 7.2 depicts the convergence of cellular and broadcast networks.

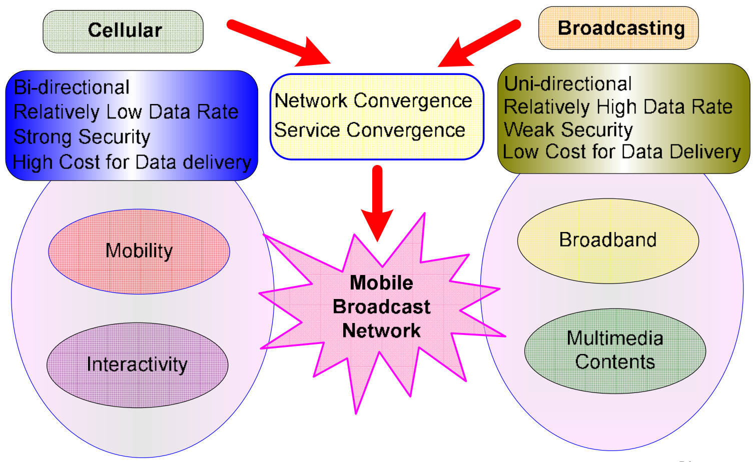

Figure 7.2 Cellular and Broadcast network convergence[51]

The DVB-H broadcast networks offer mobile TV distribution and other kinds of IP-based content delivery on a *one-to-many* basis to mobile handsets. This technology has attracted different players on the market and urged them to find a viable business model where they can cooperate. For instance, the content providers and broadcasters can focus on programming and scheduling the content. The broadcast network operators can focus on TV signal transmission, while the cellular network operators can work on offering point-to-point service transmission, such as on demand services, access security, personalization and billing.

Generally, the success and failure of DVB-H is mainly determined by the subscription revenue. Therefore, a viable business model is required to ensure long term profitability. Although the DVB-H mobile TV has already been commercialized such as in Italy and Finland, the number of mobile users is still limited. The reason is due to the fact that the main players, mobile operator and broadcast network operators have not yet agreed on a sustainable business model [9].

Different network scenarios and viable business models have been proposed for DVB-H mobile services. The realization of these models depends on different factors such as business opportunities, regulatory aspects and technical issues such as complexity, coverage and terminals costs. Figure 7.3 illustrates an example of a possible business model.

[51] Gamze Seckin, "Wireless Multicasting and Broadcasting", Fall 2006

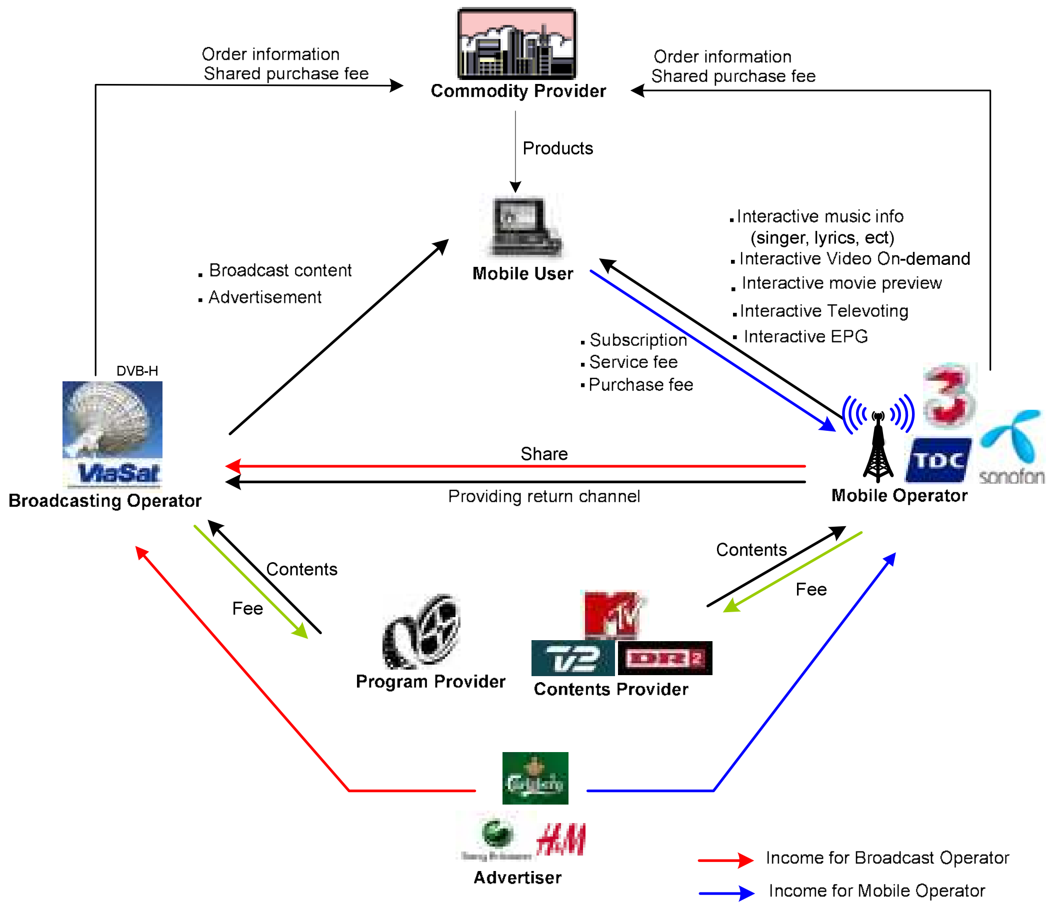

Figure 7.3 Collaboration between mobile and broadcast operators

In this model, all interactive services are handled by mobile operators. They maintain a relationship with the mobile users and handle subscriber administration details such as authentication, billing and payment. The mobile operator can increase the average revenue per user (ARPU) by retailing broadcast TV services and cellular-based interactive services such as SMS, video on-demand and E-commerce. The subscription fees and returns channel usage for televoting for instance are also sources for revenue. The broadcasting operator increases revenue mainly from service subscription fees in form of a shared revenue agreement with a cellular network operator, managing the DVB-H network, advertising revenues and other services such as e-shopping.

In addition, this business model provides an opportunity to increase revenue not only for cellular and broadcast operators but for all the players in the value chain. The content providers and program providers can also gain new revenue from delivering TV services, digital copyright and new contents to new audiences of mobile viewers. The manufacturers of mobile handsets and chip sets expand their business by selling new models of DVB-H capable mobile devices.

7.3 PAYING WILLINGNESS

The network operators who do not yet have a broadcast network in place need to switch to broadcast TV. This may however be a very difficult decision to make for the operators, as a new network has to be implemented. Moreover, it is difficult to predict how many consumers will adopt TV on their mobile handsets and whether this technology will be profitable for the operators or not.

According to Nokia research, about 24% of the active mobile phone subscribers are highly interested in adopting mobile TV services and are willing to pay around 10 to 12 € a month. Figure 7.4 below shows that 77.8% regard mobile TV as a good or excellent idea while only 7.62% disliked the idea. With this result, the mobile TV market will be quite large.

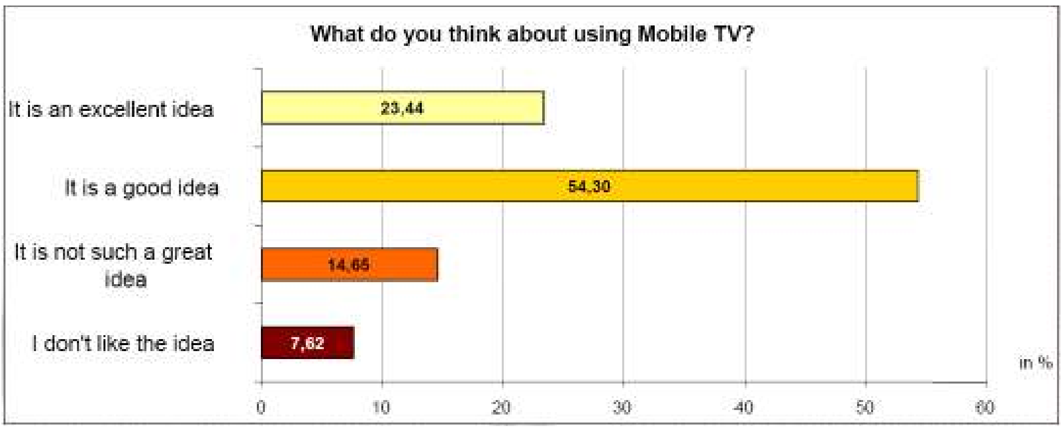

Figure 7.4 User Survey - High acceptance of Mobile TV [23]

There are two payment possibilities for the user to access TV services via his mobile handset: monthly subscription fees or pay-per-view. Market studies have shown that mobile users prefer the monthly subscription fee. The BCMO[52] study shows that mobile TV consumers are willing to pay 10-12 € (or 75-90 DKK)[53] per month to access 6 to 8 different TV channels [5].

Assuming 24% of the mobile subscribers in Denmark are willing to pay 75 DKK a month for TV services. With an estimated population of 5.4 million, the annual revenue will be $5.4 \times 12 \times 75 \times 24\% \approx 1{,}67$ billion DKK per year. With this result, DVB-H is no doubt a new source that generates increasing revenue for the service providers.

If we get back to the results found in section 7.1, one can conclude that limiting the video clips to two minutes at low-resolution and charging 0.38[54] will not attract subscribers to adopt TV on their mobile handsets. However, charging 75 DKK a month for high quality video with unlimited services makes it worth investing in this technology – a technology that will let people enjoy watching TV on the go on the mobile wherever they are and whenever they want.

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[52] http://www.bmcoforum.org

[53] Assuming currency rate (0.75)

[54] Assuming that the user will be watching on average 20 mins a day, this will be converted to around $0.38 \times 10 \times 30 \approx 114$ DKK a month day.

7.4 DVB-H NETWORK INVESTMENT

In this thesis, the cost of network investment is calculated on the basis of two groups - CAPEX and OPEX. Capital expenditures, CAPEX, consist of a fixed assets investment such as network infrastructure, network equipment etc. Operational expenditures, OPEX, include current costs such as network maintenance, support and network management.

In order to discuss the feasibility of DVB-H deployment across Denmark and estimate the cost of DVB-H network implementation, two case studies are presented in this section. They both illustrate the total cost associated with implementing DVB-H networks across the densely populated areas in Denmark. Please note that the results presented in both case studies are simply approximations and therefore not 100% accurate. The calculations are, however, based on a number of underlying assumptions.

Microsoft Excel has been used to estimate and evaluate the network cost. The network CAPEX is linked to the total cost of deployed equipment, and OPEX is mainly linked to the cost of maintenance and network capacity. The total annual cost is the sum of CAPEX divided by 3 (assuming an amortization period of 3 years)[55] plus OPEX. The total cost is also presented as a percentage of the annual subscription revenue to indicate its relative weight in the operator's budget.

7.4.1 Case Study - 1

This case study is based on the DVB-H pilot carried out by TDC. For detailed information about the pilot, please refer to the appendix A. TDC is the largest mobile operator in Denmark holding a market share of 41%[56]. Currently, TDC is in control of the 3G network with approximately 1.7 million mobile subscribers [40].

Logically, the network cost for densely populated small areas would be less expensive than for less populated large areas. This means that the financial benefit for the service provider is much higher in a densely populated than in less populated areas. From an economic point of view, offering DVB-H services outside less populated areas would not be beneficial for the service provider, unless the markets are saturated in the populated areas. Therefore, it would be a smart business decision to start from the populated areas. In addition, targeting the densely populated areas would lower the cost per user. Figure 7.5 shows the population density map of Denmark (the densely populated areas are shown in dark red, and less populated are shown in lighter red).

[55] Later in this section, when we calculate the total network implementation cost, only the annual depreciation value is included. Note that the annual interest has also been estimated to 10% and should also be included as well.

[56] This include the TDC market share 31% plus Telmore's 10% as the latter is now owned by TDC, National IT and Telecom Agency's annual report of 2006 [40].

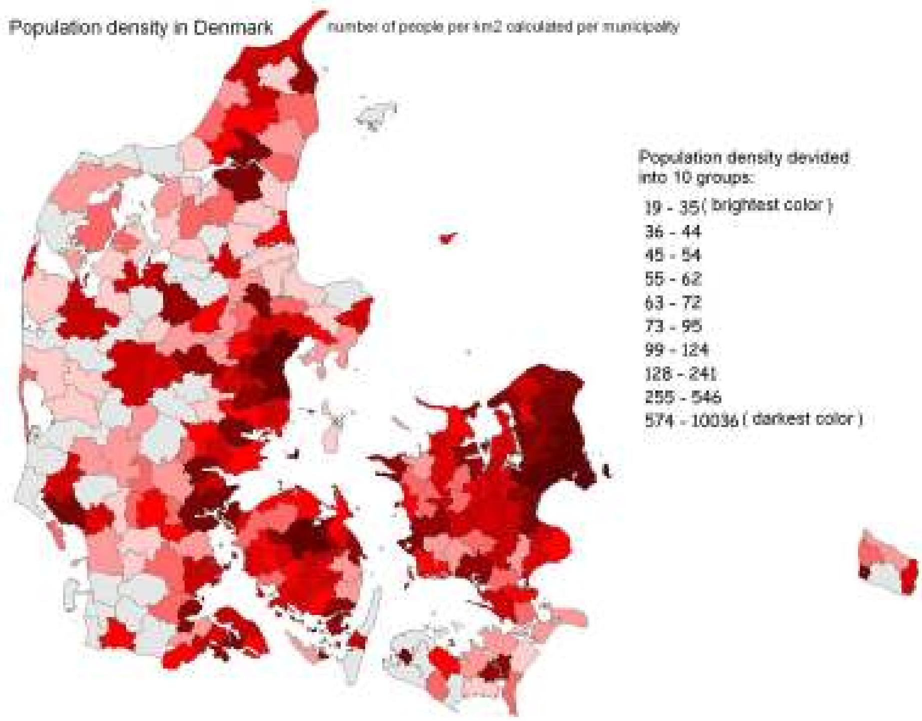

Figure 7.5 Population density in Denmark[57]

To lower the cost per person, only areas where the service is profitable are targeted in this case study. Generally, the service will be more profitable in dense urban areas. It is assumed that the DVB-H network will be deployed progressively across Denmark over the next 3 years[58] (2007-2010), starting from the most densely populated areas to less populated areas.

Denmark has a total surface area of 43,100 square kilometers and a population of approximately 5.4 million, with 85% of the population living in urban areas[59]. Most importantly, the urban areas cover only 5% or 2,155 square kilometers of the total area [41].

[57] http://www.mst.dk/

[58] The reason is that Denmark is expected to carry out a complete shut-down of analogue TV by the end of 2010.

[59] The number would have to include at the very least all people living in cities with a population larger than 10,000 people, maybe even 5,000 – which means around 65 largest cities at least [40].

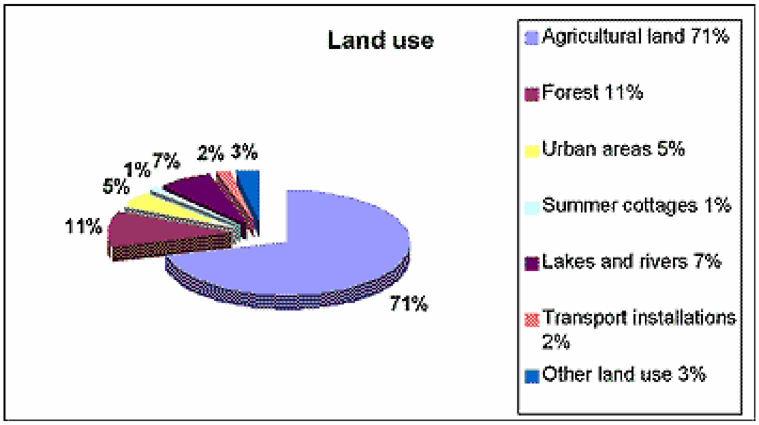

Figure 7.6 Land in Denmark [41]

Looking at the small size of the total urban areas and the associated large population density, it is without doubt areas worth targeting. The reason is that profitability can be increased while covering the majority of the Danish population. To cover all the population in the urban areas, it is assumed that the network parameters[60] and coverage probabilities used in the TDC pilot will be used in all urban areas. Note that, for simplicity's sake, it is assumed that the total revenue is based on subscription income. Income like advertisements and the amount of new subscriptions adopting new services have not been taken into account. This, however, will significantly increase the overall revenue.

Network assumptions

The network assumptions described in this section are based on the results obtained in [28] and [42]. The key finding was that to achieve indoor coverage, the DVB-H network would require similar coverage levels as 2G or 3G. According to Anssi Hoikkanen, the "*cellular site is the key factor in achieving as low site costs as possible*" [43].

Aurelian Bria and David Gómez-Barquero have investigated the feasibility of deploying DVB-H with minimum cost on an existing wireless infrastructure in a so-called hybrid cellular and DVBH system [28] [42]. They found that re-using[61] the cellular sites is a good alternative in the sense that the network operators do not need to build a new infrastructure, and thereby large network investments can be avoided. Therefore, DVB-H network deployment should be done in a similar way as the cellular systems with many sites and smaller radius. Moreover, more power[62] transmission is required in order to be able to get around the obstacles in the service area and cope with the problems caused by different phenomena such as interference and fading. These,

[60] Note that the network parameters such as modulation schemes, guard interval and transmission mode are very important in network planning. They have a great impact on the coverage area and transmission distance; consequently, it will have an impact on the required number of sites. Therefore, tuning and choosing the right network parameters would save a lot in terms of number of sites and thereby lower the overall network cost. The required number of sites is also dependent on other factors such terrain and antenna height and ERP from each sites Network planning is discussed in section 6.

[61] According to Bernd Reul from TDC re-using existing 3G site would be a good option but would require more capacity for DVB-H and consequently implies more investment on the network.

[62] This power, however, should be lower than the required power of the broadcasting sites. The reason is that the number of transmitters and repeaters co-located with 3G sites will fill the gaps and cover the critical areas. Therefore, extra power would not be needed to cover those areas.

however, can be mitigated by SFN networks because they introduce macro-diversity [63][44].

At each cellular site there is already a cable for power supply and a data connection, which makes the cost of such a deployment smaller. It should be borne in mind that installing new sites (tower, cabling, antennas, equipment, rent/month etc.) is the most costly part of a wireless network. According to Anssi Hoikkanen, the number of additional sites should be more than the number of broadcast sites, to ensure indoor coverage, but less than the number of cellular sites [43]. The reason for the latter is SFN gain [45] and that the power emitted from DVB-H receivers is higher than from traditional cellular transmitters. Note that the total number of sites, as can be seen later in this section, has a great impact on the overall system cost, because the total network cost is proportional to the number of sites.

Moreover, in order to ensure indoor coverage, a number of repeaters (gap-fillers) are required. Anssi Hoikkanen [43] claims that the number of repeaters in a large country would be roughly two times the total number of transmitters.

Since neither the number of cellular sites nor the number of broadcast sites currently deployed across Denmark are available for confidentiality reasons, it is roughly assumed that the total number of transmission sites aimed to be deployed is 250[64] (Txs) (figure 7.7). Hence, the number of repeaters should be around 500 (2×250). In addition, if we assume the number of transmitters intended to be deployed in a single SFN cell is 25, then the number of SFN cells would be 10.

[63] "Macro-diversity means a situation where several receiver antennas and/or transmitter antennas are used for transferring the same signal" www.wikipedia.org . This is an advantage because the coverage is improved by the transmitter diversity contributing in a network gain.

[64] 250 = 25×10, where 10 is the number of SFN cells in a country, and 25 is the average number of transmitters (low and high power) needed to ensure the coverage in one cell. Note also that the coverage area of each transmitter is assumed to be 25km. If we then divide the total urban area 2,155km^2 by the coverage area (25km), the required number of sites would be roughly 100 sites.

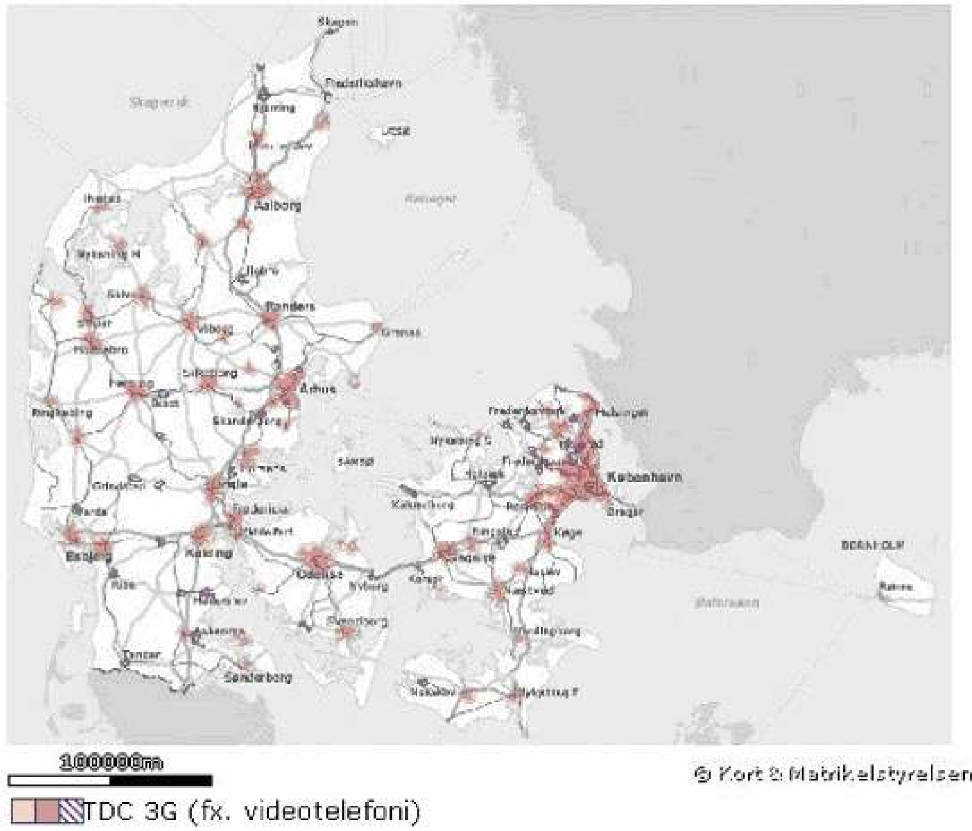

Figure 7.7 TDC 3G network coverage map (TDC website)

It is worth mentioning that the IPDC network requires other network components such as IPDC services and e-commerce systems [43]. To simplify the model these components have not been taken into consideration, although they would definitely add to the overall cost.

Note that although the differences in quality of the network equipment have a great impact on the network quality, coverage and most importantly on the overall system cost, it is assumed that the same type and quality of equipment will be deployed. The reason is that the industry does not offer DVB-H network equipment prices.

In addition, it is assumed that TDC will use its BTS sites for low power DVB-H transmission and lease broadcast towers for high power transmitters[65]. However, due to the lack of information such as leasing cost of broadcasting sites, the rental of broadcast towers that TDC might need to rent to extend the coverage area has not been included in the calculation of the network cost. Although it may add to the overall network cost, other possible costs that may arise in proportion to the quantity being used, such as power consumption and data rate, also have not been taken into consideration. The following table (Table 7.3) summarizes the capital and operational investments required for a DVB-H network installation.

[65] According to Bernd Reul from TDC, reusing existing 2G/3G sites can be an issue as we in general are moving towards lower positions, whereas DVB-H is best with higher positions. Therefore leasing some broadcast sites would be required for TDC to ensure higher cover area.

Table 7.3 Market assumptions and equipment costs[66]

Market Assumptions		Equipment costs	
Urban area[67]	65	IPE (cap) (op p.a.)[68]	224,000 DKK 22,400 DKK
		ESG(cap) (op p.a.)	200,000 DKK 20,000 DKK
Surface	2155 km^2	Encoder(cap) (op p.a.)	100,000 DKK 10,000 DKK
Cell Surface	10 km^2	Tx +Amp(cap) (op p.a.)	522,562 DKK 62,000 DKK
SFN cells	10		
Transmitters &/ Cells	25		
Gap-fillers	500	Gap-fillers (op p.a.)	179,160 DKK 22,000 DKK
Target Population	4.5 Million		
Annual Fee Per User	895 DKK	Leased line (op p.a.)	37,336 DKK
Market share	41%		
Revenue	1,651.275 Million DKK		

The DVB-H network components have been priced and estimated as follows:

- The prices of the IPE, encoder and ESG have been provided by DTU which is considered to be real prices, since DTU has bought these network components for study purposes. The operational cost of these components has been roughly estimated to be 10% of the capital expenditure.
- According to Filip Gluszak from Udcast [35], the cost of transmitter (Tx) plus amplifier (Amp) is €70,000 and the operational cost is €8,300, these are converted[69] to 522,562 DKK and 62,000 DKK respectively.
- According to the research paper [31], a 2Mbps back-haul transmission links (leased line) would cost €5,000 per year, which is converted to approximately 37,336 DKK.
- According to Pär Nygren & Mats Ek, the estimated cost for a gap filler sites using 10 W ERP is around 24 000 € per site, converted to Danish krone would be 179160 DKK [14]. The operational cost on the other hand has been roughly estimated to be 22,000 DKK.

[66] Table structure has been inspired from [35]
[67] The number would have to include at the very least all people living in cities with a population larger than 10,000 people, maybe even 5,000 – which means around 65 largest cities at least [40].
[68] Operational per annum (Latin noun meaning year: through a year)
[69] Currency rate : 1euro ≈ 7,465 DKK

Note that the set up costs of network elements have not been included.

According to Filip Gluszak [35], the average number of transmitters (low and high power) needed to ensure the coverage in one cell is 25. Hence, the total number of SFNs would be 250/25 ≈ 10. The annual fee per user has been estimated based on the survey conducted by Nokia (see section 7.1.5), which claims that mobile users would be willing to pay approximately €10 a month; this is converted to 74.65 DKK. Hence, the total annual fee per user would be 74.65×12 ≈ 895 DKK. Consequently, if we assume that the total revenue is generated from customer subscriptions then the total revenue would be (Number of subscribers × ARPU) =1651.275[70] ×24%[71] ≈ 396.306 million DKK.

Economy of DVB-H network deployment

As can be expected, achieving the required level of signal strength and optimum coverage in densely populated areas will significantly increase investments in terms of transmitters and repeaters. Figure 7.8 shows the capital expenditure of DVB-H deployment. Clearly, the transmitters and repeaters (gap-fillers) are the most costly equipment with a little more than 98% of CAPEX. This, however, is expected because the network costs for DVB-H broadcast services increase in proportion to the number of transmitters and repeaters. The number of transmitters and repeaters, on the other hand, increases with the number of sites implemented compared to the other network elements.

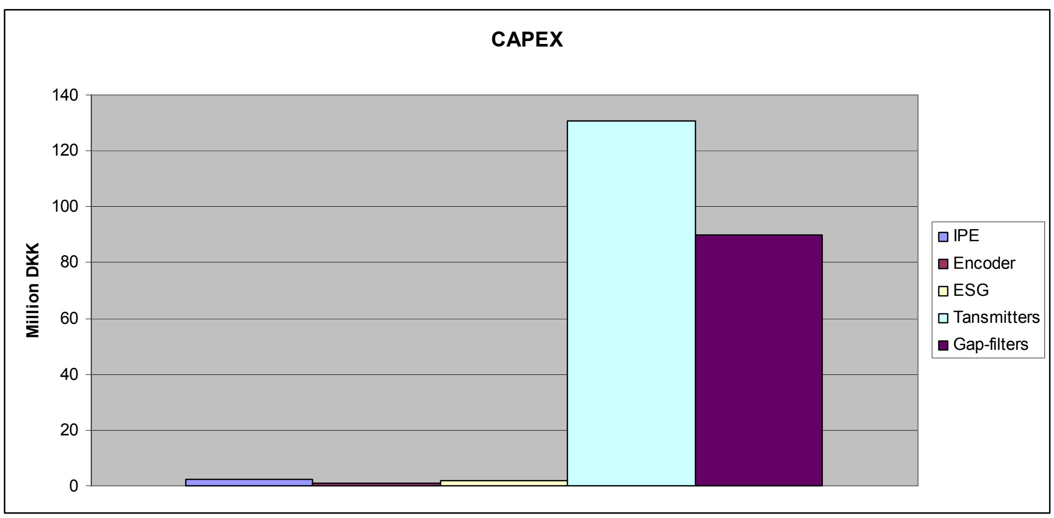

Figure 7.8 Capital Expenditures (CAPEX)

Similar to CAPEX, the operational expenses (OPEX) are proportional to the amount of network equipment used. However, in contrast to CAPEX, the operational cost will increase with the growth of the network. Figure 7.9 shows the operational expenditure of DVB-H deployment.

[70] 1,651.275 ≈ 4.5 × 895 × 41%

[71] We assumer, according to Nokia research, about 24% of the active mobile subscribers to adopt mobile TV services (see section 7.3).

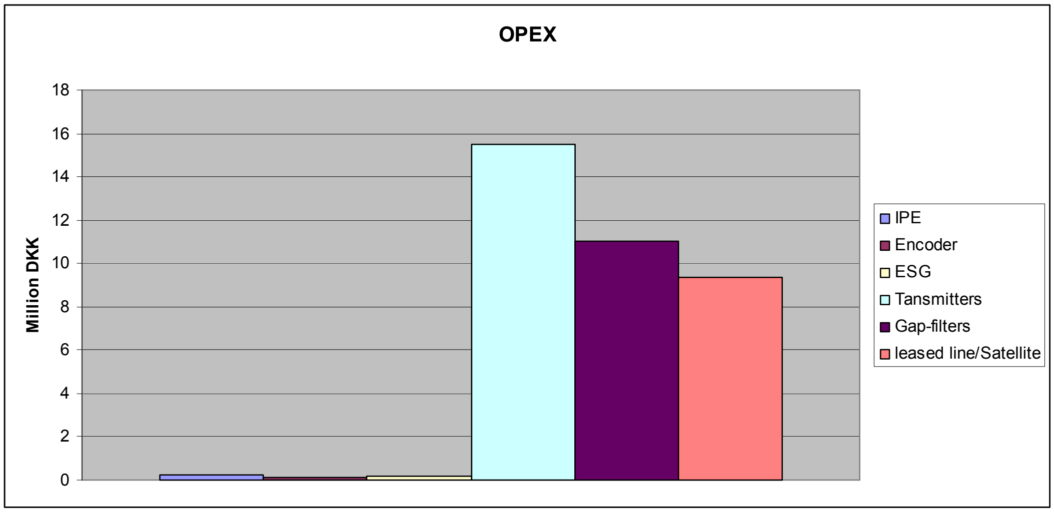

Figure 7.9 Operational Expenditures (OPEX)

Numerical results show about 36.2 million DKK OPEX (see table 7.4 below), which seems to be much lower than the annual average of 90.02 million DKK[72] CAPEX. However, this is not true as OPEX is proportional to the network growth, which is expected to increase with the growth of the network. It is worth noting that it was assumed that OPEX includes only costs for maintaining and running the network. The other possible operational costs, such as marketing, network management, spectrum and content acquisition, were not taken into consideration which may significantly add to the overall cost.

Network investment evaluation

The numerical results (see table 7.4) reveal that an investment of approximately 126,215 million DKK is required to cover the urban areas of Denmark. In other words, an investment of approximately 126.215 / (4.5 × 41% × 24%) ≈ 285.04 DKK is required per user per annum. This, however, is comparable with the annual fee per user (895 DKK), which is a good indicator that the investment cost can be recovered by the revenue generated from DVB-H services. The following table shows detailed calculations of DVB-H network investment.

[72] This is the amount that the operator would pay every year assuming a 10% annual interest rate (see table 7.4). Note that the amount has been calculated using the predefined function PMT in MS Excel.

Table 7.4 Network investment costs

DVB-H Network element (CAPEX)	price	Number	Total price
IPE	224.000	10	2240000
Encoder[73]	100.000	6	600000
ESG[74]	200.000	4	800000
Tansmitters	522.562	250	130640500
Gap-filters	179.160	500	89580000
Total CAPEX			223860500
Annual interest rate			10%
Number of years of payments			3
Annual depreciation value[75]			(kr. 90,017,621.00)
DVB-H Network element (OPEX)	**price**	**Number**	**Total price**
IPE	22.400	10	224000
Encoder	10.000	6	60000
ESG	20.000	4	80000
Tansmitters	62.000	250	15500000
Gap-filters[76]	22.000	500	11000000
leased line	37.336	250	9334000
Total OPEX			36198000
Total investement			kr. 126,215,621.00
Subscription Revenue %			31.84%

As can be seen from the results, the investment profit[77] is equal to (396.306 – 126.216) ≈ 270.1 million DKK. Hence, the subscription revenue[78] of 31.84 % (total annual cost / total annual revenue) ≈ (126.216/396.306) is a clear indication that the DVB-H network investment will be profitable[79].

The investment profitability has also been evaluated using net present value (NPV)[80]. Assuming the initial investment to be 100 million DKK and the incoming cash flows over three years is 396.306 – 126.216 ≈ 270.1 million DKK, then the NPV would be

[73] According to Filip Gluszak (VP Marketing) from UDcast we need one encoder per channel. If we assume the number of channels to be six (the same number of channels that Viasat TDC used in their DVB-H trial, see appendix A), then the required number of encoders would be six. Please note that some encoders enable encoding more then one channel in a single device (this is in fact vendors specific). Using this type of encoders would significantly reduce the required number of encoders and thereby the network investment costs would also be reduced.
[74] Due to the lack of information regarding the number of ESGs, the latter has been estimated to four.
[75] The annual depreciation value has been calculated using PMT function available on MS Excel (note that PMT function returns the payment amount for CAPEX based on an interest rate (10%) and a constant payment schedule)
[76] Note that gap-fillers do not need a transmission link.
[77] Profit = Revenue – Cost = (Subscribers * ARPU) – (CAPEX + OPEX) [83]
[78] As it has been stated earlier, the total cost is presented as a percentage of the annual subscription revenue to indicate its relative weight in the operator's budget.
[79] Although this result might sound unrealistic, one thing to remember is that these results have been obtained based on many assumptions, and many costs have not been taken into consideration. Therefore, we have to be careful in making any conclusion about whether the investment will be profitable or not
[80] Net Present Value (NPV) is a method used to evaluate the project investment.

$NPV = \sum_{t=0}^{n} \frac{A_t}{(1+i)^t} - C_0$, where A_t is the cash flow for a period t and C_0 is the initial cost of the project (Methods for evaluating investments, "Investment Theory", lecture 6) equal to 571.7 DKK. According to the economists, since the NPV is greater than zero, then the DVB-H network deployment will be profitable and should be accepted. Table 7.5 illustrates the net present value of DVB-H network investment.

Table 7.5 NPV and IRR of DVB-H investment

Data in Million DKK	Description
10%	Annual interest rate
-100	Initial cost of investment
342.486	Return from first year
342.486	Return from second year
342.486	Return from third year
Formula	**Description (Result)**
57170 %	Net present value (NPV) of this investment (NPV)
265%	Internal rate of return after five years (IRR)

In summary, from a business perspective, investing in densely populated areas will definitely increase profitability. However, revenue can be further increased by decreasing the cost of the overall network infrastructure. This can be achieved by optimizing the network infrastructure in a number of ways. These include reducing the number of sites, reducing the number of transmitters and repeaters or using higher masts with possible higher ERP [43].

In addition, although the total DVB-H network cost has been calculated based on a number of network assumptions, and many different DVB-H network components have not been taken into consideration. DVB-H seems to be profitable in the sense that the objective is to target densely populated areas.

7.4.2 Case Study - 2

In this case study, it is assumed that Broadcast Service Denmark (BSD)[81] will upgrade their existing DVB-T infrastructure to DVB-H. Figure 10 shows the DVB-T broadcast towers implemented across Denmark.

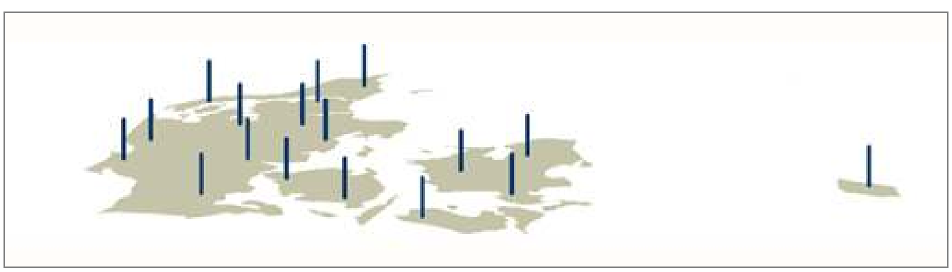

Figure 10 DVB-T broadcast towers in Denmark DIGI-TV

According to Karsten Madsen from BSD, the number of broadcast towers and repeaters deployed across Denmark is 17 and 15 respectively. Table 7.6 and 7.7 show DVB-T broadcast towers and DVB-T repeaters deployed across Denmark.

[81] Broadcast Service Denmark is a broadcast network operator (www.bsd.dk)

Table 7.6 DVB-T Broadcast towers (www.digi-tv.dk)

Master transmitter			
Sender	**Kanal**	**MHz**	**Effekt (kW)**
Hadsten	44	658	50
Hedensted	54	738	50
Jyderup	65	826	50
København	51	714	50
Nakskov	66	834	16
Nibe	29	538	50
Rø	59	778	25
Svendborg	25	506	25
Thisted	31	554	25
Tolne	29	538	10
Tommerup	25	506	50
Varde	54	738	40
Viborg	47	682	32
Videbæk	48	690	50
Vordingborg	66	834	50
Åbenrå	37	602	50
Århus	44	658	1

Table 7.7 DVB-T Repeaters (www.digi-tv.dk)

Repeaters			
Sender	**Kanal**	**MHz**	**Effekt (W)**
Frederikshavn	29	538	50
Gudhjem	59	778	50
Hadsund	29	538	50
Hammeren	59	778	100
Helsingør	51	714	200
Hobro	29	538	50
Kalundborg	65	826	100
Kolding	54	738	200
Lemvig	48	690	10
Læsø	22	482	80
Silkeborg	44	658	50
Skamlebæk	65	826	30
Struer	48	690	50
Vejle	54	738	200
Viborg By	47	682	50

Due to the country's relatively small size, it was enough to cover a total area of Denmark using a small number of high power DVB-T towers and low power repeaters. Figure 11 below depicts the coverage transmission sites across Denmark.

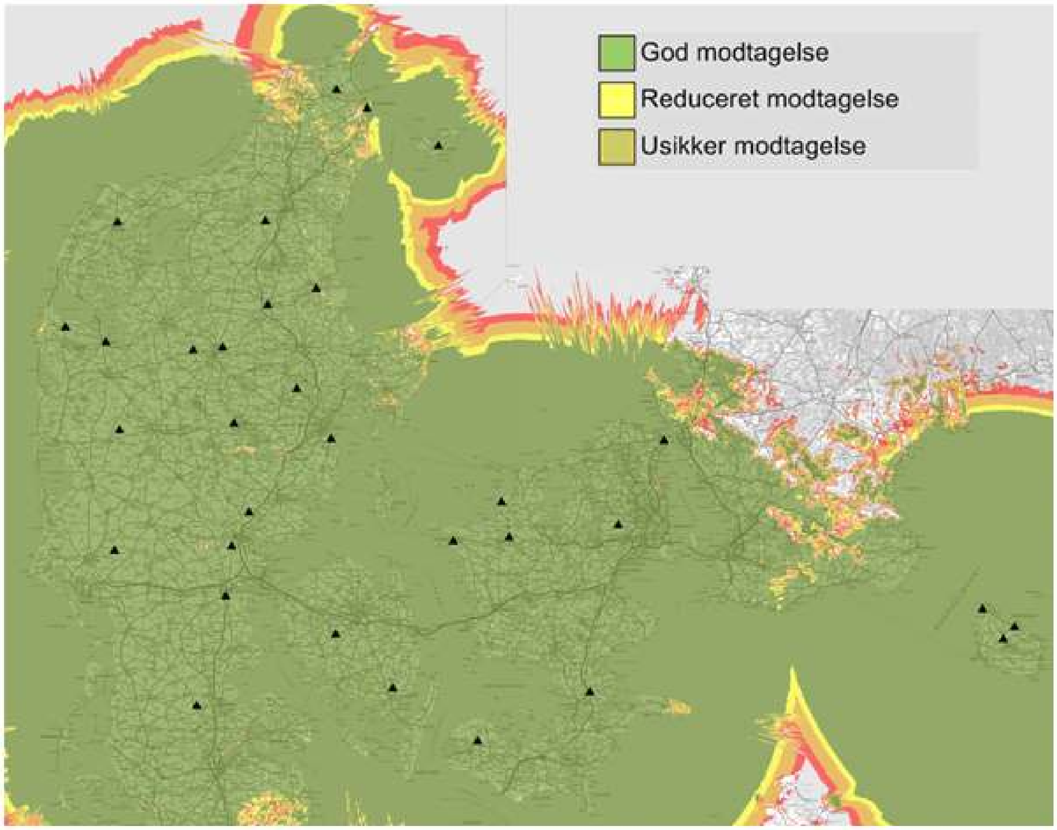

Figure 7.11 DVB-T coverage area (DIGI-TV, 2007)

Network assumptions

The network assumptions in this case study is also based on the findings obtained in [28] and [42]. The idea was that re-using existing broadcast TV networks such as DVB-T sites without adding extra sites would not be a good option. The reason is that the latter was designed for fixed roof-top antennas with line-of-sight reception conditions. Another reason is that when targeting mobile receivers, enough indoor coverage cannot be ensured.

DVB-H on other hand is characterized by not having line-of-sight conditions, large propagation loss, mobile channel interferences[82], poor reception caused by the built-in antenna, Doppler and multipath impairments [47]. Therefore, if we want to achieve the same coverage as with DVB-T and a reasonable DVB-H indoor coverage, a large number of sites is needed. This includes a number of transmitters or repeaters (gap-fillers). The latter are meant to complement the existing broadcasting towers and achieve satisfactory DVB-H coverage levels, especially in critical areas where indoor reception is required.

Alternatively, increasing the transmission power from the broadcasting towers is impractical. There are actually two restrictions that present an obstacle for increasing DVB-H transmission power. The first is due to the interference that might occur with analogue TV coverage. The second is that DVB-H transmission power cannot be increased to more than a certain limit. This is due to the exposure limits for

[82] With adjacent GSM channels and analogue TV.

electromagnetic radiation and other safety reasons defined by international regulations [42].

Based on the above findings, BSD has two options for upgrading the exiting DVB-T infrastructure to DVB-H: building a few new high-power broadcast sites or leasing many 3G sites to co-locate low-power DVB-H transmitters. According to Aurelian Bria and David Gómez-Barquero, the hybrid solution would be the best and sustainable option for broadcast network operator - as seen in the previous case study. This is because re-using existing cellular sites for DVB-H transmission would reduce investment costs and avoid large initial set up costs in network infrastructure. Hence, it is assumed that BSD will lease transmission links and BTS sites from the mobile operators.

According to Anssi Hoikkanen, the number of the additional sites should be more than the number of broadcast sites to ensure indoor coverage, but less than the number of the cellular sites. We have seen in the first case study, in order to ensure indoor coverage a number of repeaters (gap-fillers) are required. The number of repeaters in a large country would be roughly two times the total number of transmitters (see case study 1 for more details).

In accordance with his research, Tuukka Autio [31] states that the optimal network configuration would consist of a small number of large high-power transmission sites with omni-directional antennas. It also consists of several medium and small size low-power transmission sites with directional antennas. He claims also that the minimum power for large broadcast towers should be around 10kW. Whereas the minimum power for medium size sites would be around 4kW. It is therefore assumed that BSD will use its existing broadcasting sites for high-power DVB-H transmission and lease cellular base stations BST sites for low-power transmission.

Because BSD already has high-power broadcast towers in place, the number of additional DVB-H transmitters needed to ensure a plausible DVB-H network should be much less than previously assumed in first case study. Therefore, it is assumed that the total number of transmission sites aimed to be deployed besides the existing DVB-T sites is 100[83] (Txs). Hence, the number of repeaters should be around 200 (2×100) (two times the number of transmitters (please refer to case study 1 for more details). In addition, if we assume the number of transmitters intended to be deployed in a single SFN cell is 25, then the required total number of SFN cells would be 4.

[83] 100 = 25×4, where 4 is the number of SFN cells in a country, and 25 is the average number of transmitters (low and high power) needed to ensure the coverage in one cell. In fact the required number of DVB-H transmitters co-located with the cellular base stations depends on the power emitted from the existing broadcasting towers and the EIRP planning at cellular sites. Please refer to figure E.4 in the appendix that shows EIRP at cellular site as a function of the number of sites employed. According to Aurelian Bria [48], for 95% indoor coverage, a 50dbW transmitter placed on traditional broadcast tower (150m), would replace about half of the required cellular sites. Hence, if we assume all the broadcasting towers to be deployed to have the same type and quality (50dBW with height of 150m), the number of the required transmitters would be 100 (almost half the number of cellular sites assumed in the first case study).

Tuukka Autio also writes that according to data from Nokia, a DVB-H rental site would cost around 20,000 € or 149,286[84] DKK to set up, and 1,000 € or 7,464 DKK as operational cost. He also mentioned that a 2Mbps link would cost 5,000 € or 37,321 DKK per year. In fact, he mentioned other prices which are not included because the idea is to merely get a price that is reasonable and close to the real situation. It is worth mentioning that leasing the cellular sites from the mobile operators, implies also leasing costs that is proportional to the number of leased sites as well as the transmission links.

As assumed in the first case study, other network components such as IPDC services and e-commerce systems have not been taken into consideration, even though they would add to the overall cost. Also, because the industry does not offer DVB-H network equipment prices, it is assumed that the same type and quality of equipment will be deployed.

Although it may add to the overall network cost, other possible costs that may arise in proportion to the quantity being used, such as power consumption and data rate, have not been taken into consideration either. The following table (Table 7.8) summarizes the capital and operational investments required for a DVB-H network installation.

Table 7.8 Market assumptions and equipment costs

<table>
<tr><th colspan="2">Market Assumptions</th><th colspan="2">Equipment costs</th></tr>
<tr><td rowspan="2">Larger cities</td><td rowspan="2">65</td><td>IPE (cap)
(op p.a.)</td><td>224,000 DKK
22,400 DKK</td></tr>
<tr><td>ESG(cap)
(op p.a.)</td><td>200,000 DKK
20,000 DKK</td></tr>
<tr><td>Surface</td><td>2155 km^2</td><td>Encoder(cap)
(op p.a.)</td><td>100,000 DKK
10,000 DKK</td></tr>
<tr><td>Cell Surface</td><td>10 km^2</td><td rowspan="3">Tx +Amp(cap)+Set-up
(op p.a.)[85]</td><td rowspan="3">671,848 DKK
7,464 DKK</td></tr>
<tr><td>SFN cells</td><td>4</td></tr>
<tr><td>Transmitters &/ Cells</td><td>25</td></tr>
<tr><td>Gap-fillers</td><td>200</td><td rowspan="2">Gap-fillers
(op p.a.)</td><td rowspan="2">179,160 DKK
22,000 DKK</td></tr>
<tr><td>Target Population</td><td>4.5 Million</td></tr>
<tr><td>Annual Fee Per User</td><td>895 DKK</td><td rowspan="3">Site maintenance cost

Electricity + reserve power

Cost of distribution feedlines (op p.a.)</td><td rowspan="3">37,325 DKK

7,465 DKK

74,650 DKK</td></tr>
<tr><td>Market share</td><td>41%</td></tr>
<tr><td>Revenue</td><td>1,651.275 Million DKK</td></tr>
</table>

[84] Note that this amount is added to the overall cost of transmitter (Tx) plus amplifier (Amp) (149,286 + 522,562 ≈ 671,848 DKK) assumed in the first case study (see Table 7.8).

[85] Operational per annum (Latin noun meaning year: through a year)

How the DVB-H network components have been priced and estimated can be found in the previous section (study case 1). Note that as opposed to table 7.3 (case study 1), two operational cost have been added. Note that the prices are in accordance with the findings reported by Pär Nygren & Mats Ek [14]

- DVB-T site maintenance cost would cost around 4000-6000 Euros, we then roughly estimate the DVB-H site maintenance to be around 5000 euro; converted to 37325 DKK
- Electricity + reserve power 1000 Euros /Year; converted to 7,465 DKK
- Cost of distribution feed-lines 10000 Euros/ Year; converted to 7,4650 DKK

Note also that with the exception of the DVB-H set up site, other network components have not been included.

Additionally, as explained earlier, and according to Filip Gluszak [35], the average number of transmitters (low and high power) needed to ensure the coverage in one cell is 25. Hence, the total number of SFNs would be 4×25 ≈ 100. Also, the annual fee per user has been estimated based on the survey conducted by Nokia (section 7.3), which estimated that mobile users would be willing to pay approximately €10 a month. This is then converted to 74.65 DKK. Hence, the total annual fee per user would be 74.65×12 ≈ 895. Consequently, if we assume that the total revenue is generated from customer subscriptions then the total revenue would be (Number of subscribers × ARPU) =1651.275[86] ×24%[87] ≈ 396.306 million DKK.

Note that because BSD is offering free-to-air channels. This makes it (according to Karsten Madsen from BSD) difficult to estimate the number of subscribers[88]. Therefore, it is assumed that BSD market share is equal to 41% (the same as for TDC).

Economy of DVB-H network deployment

Similar to first case study, the total CAPEX is proportional to the number of transmitters and repeaters. Figure 7.12 shows the capital expenditure of DVB-H deployment on top of the existing DVB-T network infrastructure. Obviously, the cost of DVB-H implementation is mainly affected by the number of transmitters and repeaters with more than 95% of CAPEX.

[86] 1,651,275 ≈ 4.5 × 895 × 41%

[87] We assumer, according to Nokia research, about 24% of the active mobile subscribers to adopt mobile TV services (see section 7.3).

[88] According to Karsten Madsen, this problem will be resolved with the analogue TV shutdown by the end of 2010.

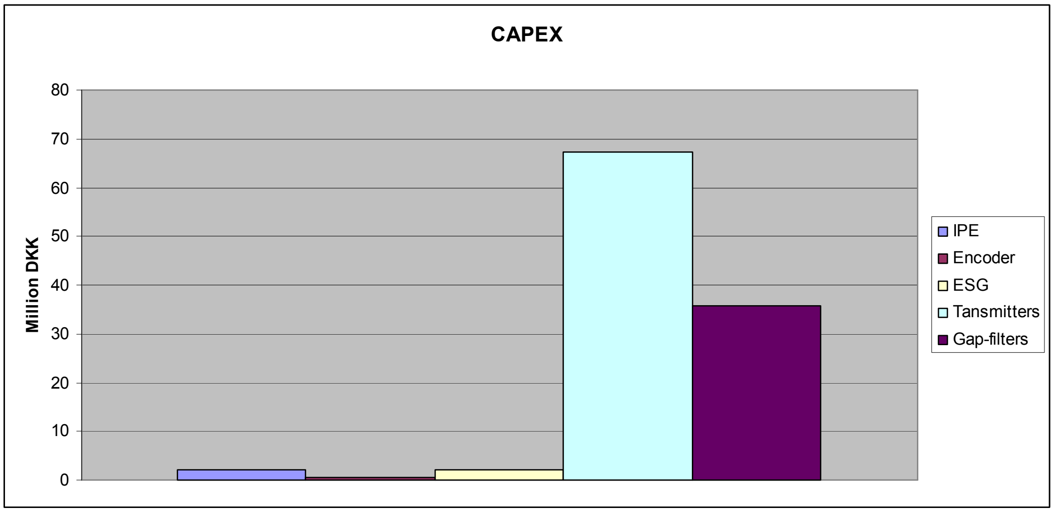

Figure 7.12 Capital Expenditures (CAPEX)

The operational expenses (OPEX) are also proportional to the number of network elements being used. These expenses are further expected to increase with the network growth. Figure 7.13 shows the operational expenditure of DVB-H deployment on top of the existing DVB-T network.

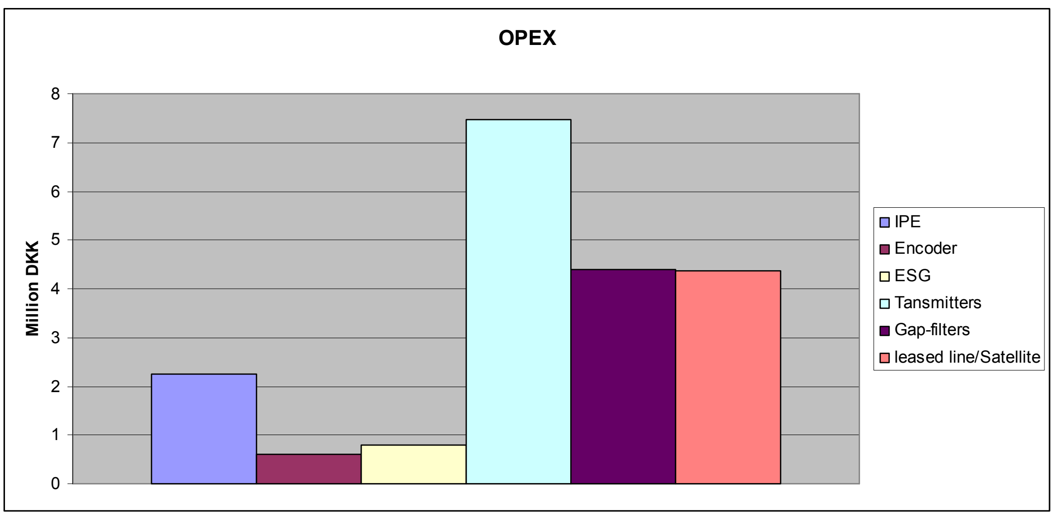

Figure 7.13 Operational Expenditures (OPEX)

Numerical results reveal that the operational cost is around 17.45 million DKK. Although it is initially lower than the CAPEX with 43.37[89] million DKK, it will still increase with the network growth since the OPEX is proportional to the network growth, unlike CAPEX.

Note also that it was assumed that OPEX only includes costs for maintaining and running the network. The other possible operational costs, such as marketing, network management, content acquisition, etc., were not taken into consideration which may add to the overall cost.

[89] Remember that this is a depreciated value.

Discussion

Numerical results show that an investment of approximately 60.82 million DKK is required to cover the entire country. In other words, an investment of approximately 60.82 / (4.5 × 41% × 24%) ≈ 137.35 DKK is required per user per annum. Again, if we compare the latter with the annual fee per user (895 DKK), then it is a clear indication that the service will be beneficial and that the investment cost can be recovered by the generated revenue from DVB-H services. Table 7.9 illustrates the detailed calculations for DVB-H network cost.

Table 7.9 Network investment costs

DVB-H Network element (CAPEX)	price	Number	Total price
IPE	224.000	10	2240000
Encoder	100.000	6	600000
ESG	200.000	4	2000000
Tansmitters	671.848	100	67184800
Gap-filters	179.160	200	35832000
Total CAPEX			107856800
Annual interest rate			10%
Number of years of payments			3
Annual depreciation value[90]			(kr. 43370815.95)
DVB-H Network element (OPEX)	**price**	**Number**	**Total price**
IPE	22.400	10	224000
Encoder	10.000	6	60000
ESG	20.000	4	80000
Tansmitters	7.464	100	746400
Gap-filters	22.000	200	4400000
Site maintenance cost	37.325	100	3732500
Electricity + reserve power	7.465	100	746500
Cost of distribution feedlines	74.650	100	7465000
Total OPEX			17454400
Total investement			kr. 60,825,215.95
Subscription Revenue %			15.35%

Similar to case study 1, the DVB-H shared network with DVB-T is no less profitable. If we assume the initial investment to be 100 million DKK and the incoming cash flows over three years is 396.306 – 60.82 = 335.486 million DKK, then the Net Present Value (NPV) would be equal to 734.30 DKK. According to the economists, since the NPV is greater than zero, then the DVB-H network deployment will be profitable and should be accepted. Table 7.10 illustrates the net present value of DVB-H network investment.

[90] The annual depreciation value has been calculated using PMT function available on MS Excel (note that PMT function returns the payment amount for CAPEX based on an interest rate (10%) and a constant payment schedule)

Table 7.10 NPV and IRR of DVB-H investment

Data in Million DKK	Description
10%	Annual interest rate
-100	Initial cost of investment
370.386	Return from first year
370.386	Return from second year
370.386	Return from third year
Formula	**Description (Result)**
73430%	Net present value of this investment (NPV)
331%	Internal rate of return after five years (IRR)

In summary, comparing the profitability of implementing the DVB-H network using existing cellular networks (case study -1) or on top of existing DVB-T networks (case study -2), it looks like the network investment in the shared DVB-H/DVB-T network is the better option. This can also be seen using the project investment evaluation methods. Clearly, NPV2 with 734.3 DKK is much higher than NPV1 with 571.7 DKK. Similarly, looking at the IRR[91] of both network investments, IRR2 with 3.31 is higher than IRR1 with 2.65. Although both investments are profitable[92], we conclude that the investment into a shared DVB-H/DVB-T network would be better and more profitable than a dedicated DVB-H network using existing cellular mobile networks.

Although it seems there is not a big difference between the two investments, it is worth mentioning that the DVB-H/DVB-T shared network has an advantage in terms of network cost because there is no spectrum acquisition associated with it. The broadcast network operators have already invested in the license of the spectrum, allowing them to utilize it for DVB-H without further investment in frequencies. The acquisition cost of the spectrum would significantly add to the overall network investment in case of the dedicated DVB-H implemented on a 3G network.

[91] Internal Rare of Return (IRR) is the most widely comparison method used by engineers and business managers to evaluate the capital projects (Methods for evaluating investments, "Investment Theory", lecture 6).
[92] This can also be seen by comparing the subscription revenue% of the two investments. The first subscription revenue with 31.84% is larger than the subscription revenue% of the second investment with 15.35%. This is also a clear indication that the investment on shared DVB-H network offer lower capital and operation cost.

7.5 FUTURE MARKET FOR MOBILE TV

"*Early market research indicates that both television broadcasters and cellular service providers would be able to launch profitable service offerings around mobile TV technology*" [6].

The market forecasts for mobile TV are based on both broadcast and unicast streaming technologies. Forecasters are expecting that unicast TV streaming technology will be the dominant technology in the short term. In the longer term, however, TV broadcast technology will prevail as the number of mobile TV users increases. The reason is that the unicast streaming video is not suitable for a mass market adoption of mobile TV, whereas video broadcasting can reach mass audiences not only at home but also while on the move.

Forecasters are also expecting a steady growth in video streaming services, but this will be decreasing again as the broadcast technologies penetrate the market. Experts expect a high adoption rate of broadcast technologies by 2010 where the analogue TV shutdown is expected, releasing more spectrum for mobile TV services. They also expect the highest percentage rate of DVB-H amongst other available technologies on the market. This was based on for instance the number of tests taking place in different countries around the world. Figure 7.14 shows the total revenue for streamed and broadcast services.

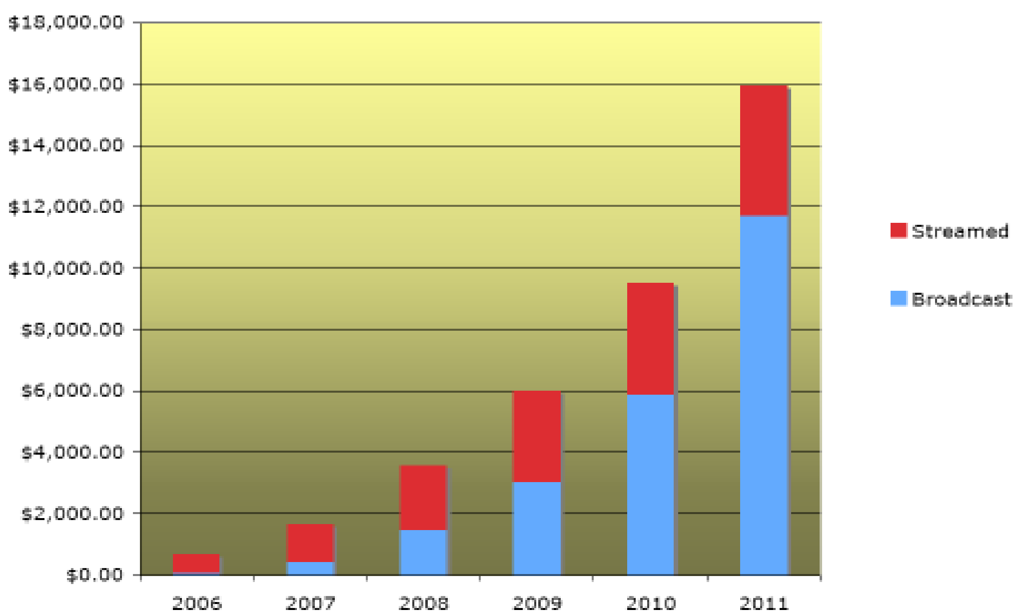

Figure 7.14 Total Revenues for Streamed and Broadcast Mobile TV Services, 2006-11($m) [49]

It is obvious from the figure above that the unicast streaming services have been and will be the dominant technology with around $583.4 million in 2006 compared to broadcast services with $94.57 million in total revenue. However, this will not be the case in the near future as the broadcast technology will overtake the streaming services. Eventually, from 2008 we will witness a rapid growth for mobile TV broadcasting reaching $11.7 billion by 2011 compared to $4.2 billion for streamed services [49].

In addition, market analysts ABI[93] research forecasts that the global market of TV services will grow exponentially from less then a million of users today to about 250 million users by the year 2010. This, however, will result in increasing the market exponentially to approximately $27 billion or approximately €20 billion [2].

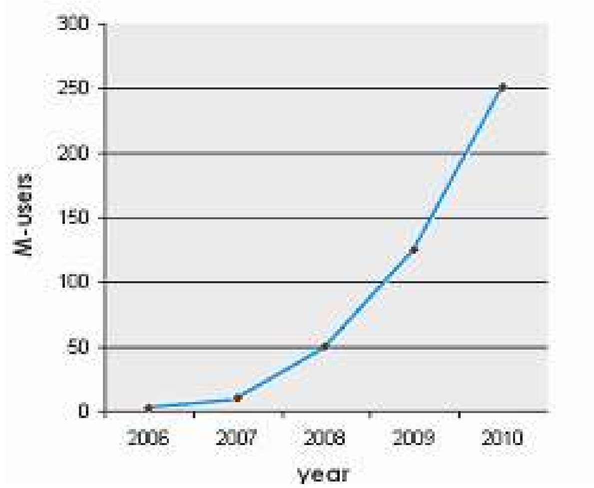

Figure 7.15 Mobile TV users [2]

Furthermore, Surveys conducted in different countries in Europe have shown viewers' interest in watching TV on their mobile handsets. The study revealed that 40 to 60% of mobile subscribers are interested in receiving TV on their handsets and are willing to pay €10 a month for the service. The studies conducted by the BCMO project (see Figure 7.4, page 55) has shown that around 77.8% of mobile users felt that having TV on the handset was an excellent or good idea. These results are a good sign that the market for mobile TV services on handheld devices will grow quite large. Especially since the technology is targeting a huge number of audiences counted as individuals, as opposed to counted as household users. The following table (Table 7.11) describes the different market research companies on mobile TV.

93 http://www.abiresearch.com/home.jsp

Table 7.11 Forecasts on mobile TV [9].

Market research company	**Forcast**
ABI Research	○ Mbile TV sales will be USD 27 million in 2010
eMarketer	○ More than 100 million people will watch paid or sponsored mobile broadcast video by 2009
Gartner	○ 10 per cent of all mobile phone users will subscribe to mobile TV by 2009.
IDC	○ 24 million paying for TV/mobile content on their mobile devices in US by 2010, under 10 per cent of all subscribers.
IMS Research	○ 446 million people will be watching TV on mobile handsets worldwide by 2011
Infonetics	○ Mobile Video from 46.2 million in 2005 to 5.6 billion in 2009 worldwide. Half of the subscribers will be in Asia.
Informa	○ 124.8 million broadcast users worldwide in 2010. ○ More than 50 million DVB-H phones sold worldwide by 2010.
InStat	○ 94 million mobile TV subscribers in China by 2009.
Juniper Research	○ Broadcast mobile TV revenue will be USD 11 billion worldwide by 2011.
Jupiter Research	○ 65 million mobile TV subscribers worldwide by 2010.
Strategy Analytics	○ More than a quarter of digital TV devices will be mobile phones in 2010.

7.6 EVALUATION OF RESULTS

Although it brings great challenges, DVB-H can without doubt offer new opportunities both to broadcasters as well as to mobile operators. The results obtained showed that plenty of revenue can be generated from mobile TV consumers. However, caution has to be taken when interpreting the results, because as it has been stated, the network investment is based on a number of underlying assumptions. Other generated revenue sources which have not been included in the analysis, such as advertisements income, can add even more to the overall revenue. The surveys and pilots conducted across the world show that there is great demand and huge interest from mobile users willing to adopt the new mobile TV services on their handheld devices.

Now it is clear that the mobile networks with their limited bandwidth capacity including 2.5G and 3G, even with the latest new emerging technologies MBMS and HSPD, are not scalable and unable to reach a large number of simultaneous mobile users. The broadcast networks with their high capacity are the best suited to target mass audiences with high quality of service and low cost. In particular the European standard DVB-H is no doubt the best candidate to satisfy the customer demand of multimedia mobile TV services. This, however, does not mean that the mobile networks will not be needed; they actually complement the broadcast network.

Although the results may sounds too optimistic, it has to be borne in mind that the results were based on a number of underlying assumptions and results obtained from the different sources and published papers available on the internet. The DVB-H network investment looks profitable (only when there is a strong consumer demand and a mass market). Unfortunately, there is no comparable data available to prove this assertion. It has also been shown that the service generate significant return on investment. It is worth mentioning that the profitability of a DVB-H network investment is mainly based on the number of mobile TV consumers and on the return-on investment that the broadcasters would get. If there are only few mobile TV consumers, then the required large investment to a build DVB-H broadcast network would not make sense and would only be considered as waste of money.

The question that will remain outside the surveys and analysts reports is whether there really is consumer demand for mobile TV services. Will people need this technology? According to the survey conducted in Hong Kong by Guan Wang [50], out of 432 people who were questioned, 63% of them said they do not need to use the mobile TV service. 44% were more concerned about the price and said that the price was the reason for not being interested. The Danes are no less cautious about spending their money on mobile services than other people of the world, so reasonable pricing would be another issue that the service providers should consider.

According to Statistical Yearbook 2006, the Danish population is getting older. This means that the age will play a huge role in the mobile TV service adoption because if we take the early adopters group of mobile services, aged 15-24, which is considered to be the most attractive market segment [46], then only around 11.43% of the population will be especially interested in mobile TV services. This means that the total revenue will decrease (see Figure E.6 in the appendix E).

8. CONCLUSION AND FUTURE WORK

8.1 CONCLUSION

Mobile TV services in Denmark are being offered nowadays on cellular 3G networks. For the next couple of years, with the investment on the next generation technologies such as HSDPA we expect these networks along with their higher capacity to remain the dominant carrier for mobile TV services. However this trend will only continue as long as these networks are able to meet the requirement of the growing demand of multimedia services. When these networks are saturated the cellular Danish network operators will have no option but to switch to a more cost-effective solution for the delivery of mobile TV services.

To keep up with this increase in demand, mobile networks will need to switch from point-to-point unicast transmissions to large scale broadcasts. Among different broadcast technologies available on the market, the standard DVB-H has proved to be the right candidate to be deployed in Europe as it is capable of delivering mobile TV to large number of simultaneous users cost-efficiently. Another interesting prospect provided by DVB-H IP-Datacast is the possibility of a combination of cellular and broadcast networks in a hybrid network. The convergence of these two communication systems would enable us to use the advantages of the two way mobile systems alongside a broadcast network.

A combination of mobile broadcast TV (DVB-H) together with 2.5G and 3G networks will offer a better user experience as well as more efficient utilization of the operators' spectrum and resources. 3G cellular networks are also expected to be complementary for the successful mass market deployment of DVB-H. The possibility of implementing the DVB-H network on top of the existing 3G and DVB-T network infrastructure is also appealing since it means that the initial network investment is much lower.

The main constraint to implementing DVB-H at the moment is that it is restricted due to the scarce spectrum. The implementation of DVB-H therefore relies on the spectrum which will be made available in 2009 when analogue TV is expected to shut down. However, to build the DVB-H network, broadcasters will have to wait for the government to decide which frequencies will be made available for mobile TV networks. It is, however, expected that mobile TV services and other mobile multimedia are likely to show significant growth in the near future, not only in Denmark but in many countries around the world.

The expectation to the growth of Mobile TV provides an opportunity for broadcast and mobile companies alike to make new revenue. The mobile and broadcast operators should therefore co-operate on providing these services since the mobile operators have a large customer database and a complete commercial infrastructure for a mass market mobile TV service, something that the broadcasters lack.

The gains or losses will depend on the initial investment spent on setting up the infrastructure. The network cost as the key aspect is critical for the future of the broadcaster. As DVB-H is rolled out, great new opportunities are offered for all the players in the value chain to earn money. The success of DVB-H is dependent on a viable business model and alliances with all the players in the value chain. Without this, the DVB-H concept will probably never reach its potential.

This thesis can hopefully be used by all parties interested in providing DVB-H mobile TV services. The case studies described can be a good reference for further studies and initial step in estimating the cost of implementing the DVB-H network. To conclude, the results obtained in the case studies proved that it is possible to implement the network. Although the results may be too optimistic, this should encourage both cellular network providers and TV broadcasters to cooperate in the implementation of DVB-H. The DVB-H trials conducted by Viasat and TDC have revealed user acceptance and willingness to adopt and pay for the TV mobile services. We expect this trial will help to promote the deployment of DVB-H mobile TV service in Denmark. The only thing that remains now is a company willing to take the risk to launch mobile broadcast television successfully in Denmark.

8.2 FUTURE WORK

The study presented in this thesis was based on many assumptions and results obtained from published papers. It would therefore be interesting to re-do the cost estimation when the prices of the different components are available to the public, maybe with a longer perspective than 3 years.

It would also be interesting to prove the results claimed by the authors using some simulator software. However for this, a more realistic network investment model would need to be made and other factors and network components, such as content rights, spectrum acquisition and taxes, would also need to be included in the estimation of the overall network cost.

The discussion about other existing technologies could also be expanded. MBMS and HSDPA are mentioned as interesting new technologies with growing popularity. It would be interesting to study how a market for mobile television can look with these technologies - and which operators, payment models and content could be relevant. Two study cases were identified, one for a dedicated DVB-H network and the other for a shared network with DVB-T. A more extensive analysis could be to identify additional study cases, which would add more risk.

Moreover, the prices of the components change with the course of time. It will be interesting to see how the OPEX changes over the next couple of years. Redoing the calculation over a longer time period, and the analysis at a later occasion, would probably lead to entirely different conclusions. It would also be interesting to replace the assumptions with the real data and see what the impact would be on the results

Last but not least, the DVB-H technology is an interesting subject. It would also be nice to include all the costs associated with DVB-H implementation to get a real picture of how much the network would cost.

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APPENDICES

A. VIASAT-TDC DVB-H PILOT

In June 2007, TDC[94] Denmark conducted a DVB-H pilot. The test network consists of a one-tower transmitter to cover part of the Copenhagen metropolitan area with a sufficiently large population. The network covers approximately 1/9 of the total Danish population[95]. This is corresponds to approximately 97.02 km^2[96]. A pilot test consists of a DVB-H unidirectional point-to-multipoint network which has been set up in cooperation with Nokia and Viasat. Figure A.1 shows the Viasat-TDC planning area of the end-to-end system transmission based on DVB-H.

Figure A.1 Viasat-TDC DVB-H planning Copenhagen area

The main objectives of the pilot test were as follow:

- Implementation of a mobile multimedia broadcast system using IP Datacast over a DVB-H transmission.
- Demonstrating the possible use of the combined cellular and broadcast systems and services.
- Investigation of the technical performance of the DVB-H system and potential DVB-H network coverage.
- Testing the robustness of DVB-H transmission as well as learning users' viewing experience and service acceptance.

[94]www. tdc.dk
[95] According to Statistical Yearbook 2006, the total Danish population is 5,427,459 [40].
[96] The total surface area of Denmark is 43,098.31(Statistical Yearbook 2006) [40]

A.1 System Test Setup

The system setup that has been implemented by Viasat-TDC is a simple DVB-H broadcast network with only one broadcast tower. The DVB-H broadcast network has been used for mobile TV broadcast transmission. Figure A.2 illustrates the system platform of the Viasat-TDC network.

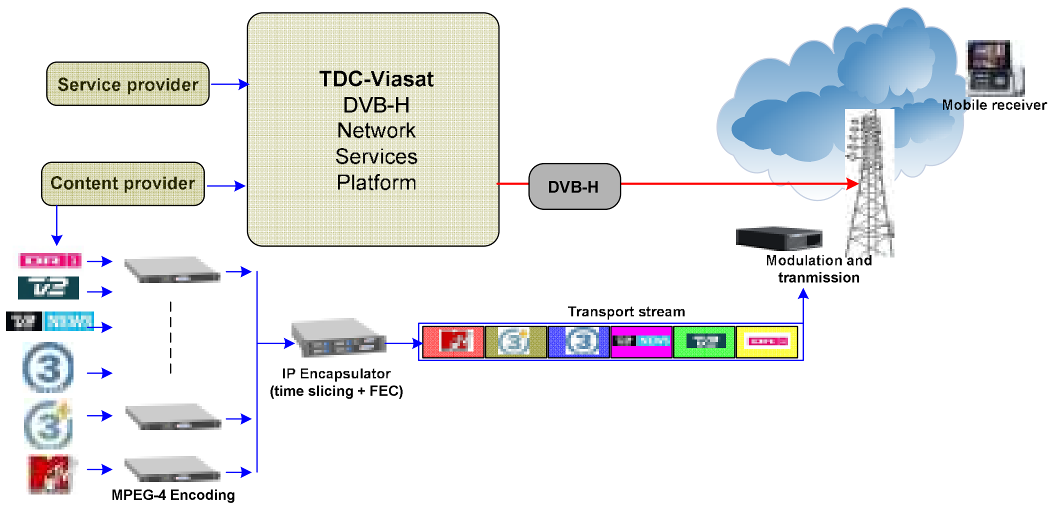

Figure A.2 The TDC-Viasat hybrid platform

As shown in the figure above, the pilot project involves transmission of six TV channels (DR1, TV2, TV2 News, TV3, TV3+, MTV) to 50 users in the Copenhagen area. Two mobile handsets were used in this pilot: Nokia N92 and Nokia N77 DVB-H enabled handsets. At the time of writing, the test was to be completed by mid-July 2007.

A.2 DVB-H transmission

As mentioned earlier, the Viasat-TDC system consists of one broadcast tower situated close to the center of Copenhagen city in Lynetten[97] with 8 kW ERP and 90m in height. The network parameters have been set up to achieve a reliable indoor and outdoor mobile reception. This include QPSK 8 K mode, 1/4 guard interval and 1/2 code rate. With this setting, a data rate of 4.97 Mbps is achieved. In addition, TDC aims to transmit a service of mobile TV in a single 8MHz DVB-H channel. The TV broadcast transmission channel being used is UHF channel 49 [698MHz][98]. The general information about the Viasat-TDC DVB-H Pilot is further summarized in table A.1 below.

[97] Lynetten is a place situated in the Copenhagen municipality.

[98] This frequency is considered usable in case the GSM900 is used in a convergence handset [15]. It avoids cellular interoperability issues with GSM 900 as the interference with GSM at this frequency will not cause a problem.

Table A.1 The Viasat-TDC DVB-H Pilot [51]

GENERAL INFORMATION		
LOCATION		Copenhagen, Denmark
PARTICIPATING COMPANIES		Viasat/Modern Times Group (MTG), TDC
DURATION		June-July 2007
AIMS & OBJECTIVES		Showcasing DVB-H in Denmark Getting usage data from Danish consumers Gaining experience on DVB-H systems including CAPEX/OPEX
BUSINESS MODEL(S) INVESTIGATED		n/a
USERS		>20 pilots + >30 one-off testers
SERVICE CONTENT		6 channels (DR1, TV2, TV2 News, TV3, TV3+, MTV)
TARIFFS / PRICING LEVELS		n/a
TECHNICAL INFORMATION		
TRANSMITTERS		1 Transmitter
BROADCAST BAND AND FREQUENCY		Channel 49 (698Mhz)
DVB-H PARAMETERS	**Bandwidth**	8 MHZ
	Constellation	QPSK
	Code Rate LP	½
	Code Rate HP	½
	Guard Interval	¼
	Transmission Mode	8k
AMOUNT OF BANDWIDTH USED FOR DVB-H		4,97 Mbps
VIDEO FORMAT		H.264
INTERACTIVITY PLATFORM		Nokia BMS
CONDITIONAL ACCESS / DRM TYPE AND PROVIDER		n/a
HEADEND EQUIPMENT		Nokia ESG system, Envivio Encoders
RECEIVER / TERMINAL EQUIPMENT		Nokia N92 and Nokia N77
TRANSMITTER DATA		
Coordinates		12E36 49 / 55N41 50
Frequency		698.000 MHz
Power (ERP)		8 kW (70dBm)
Height (AMSL)		3
Antenna Height		90
Polarization		Vertical
Name		Lynetten

A.3 Network coverage targets and analysis

The coverage area that Viasat-TDC is currently planning is depicted in Figure A.3.

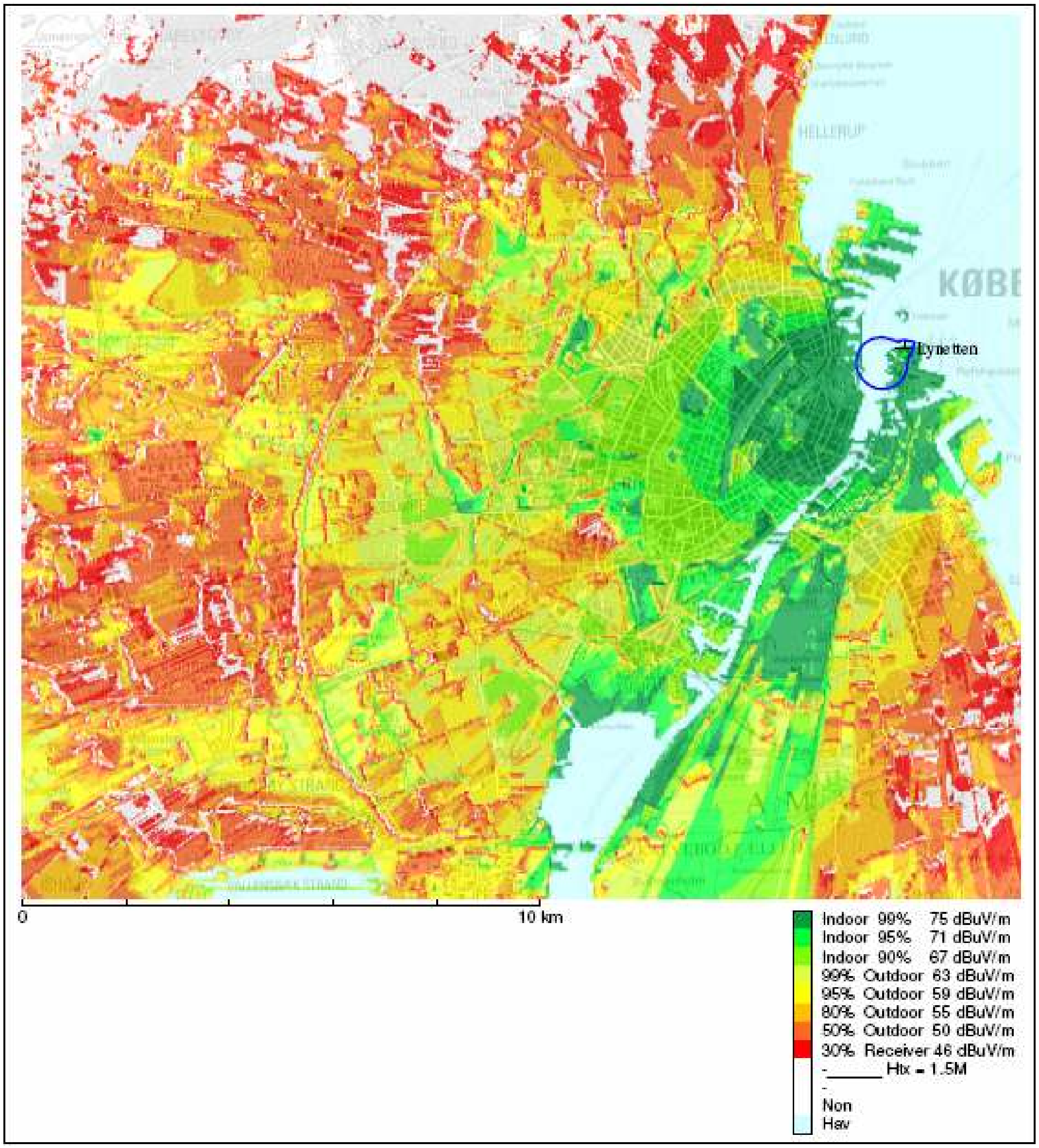

Figure A.3 Viasat TDC DVB-H planned coverage area (Viasat-TDC pilot, 2007)

Figure A.3 above shows the simulation result of the covered target areas. Although only one broadcast tower with a height of up to 90m and 8kW ERP has been used, it can be seen that good indoor coverage can be achieved. The simulation result shows a signal strength of 75dBuV/m with 99% indoor reception probability (dark green) in the small area around the main transmitter. It can also be seen that the same mobile reception probability is achieved in the areas that are in a direct line-of-sight to the transmitter. It also shows indoor coverage with 71dBuV/m at 95% and 67dBuV/m at 90% coverage probability (light and very light green, respectively). In addition, the outdoor coverage area is larger than the indoor coverage. This is because outdoor reception does not suffer loss of signal quality (e.g. building penetration loss) as indoor reception does. The result shows a signal strength of 63dBuV/m with a 99% outdoor reception (dark yellow) and from 55dBuV/m to 59dBuV/m with 80% to 95% outdoor reception (light and very yellow, respectively). Logically, the signal level gets worse as we move away from the broadcast tower, 30% to 50% outdoor reception with a signal strength of 50dBuV/m to 46dBuV/m, respectively.

Obviously, a network based on only one high-power transmitter is not sufficient to ensure mobility and good indoor coverage. However, to achieve large indoor coverage and sufficient field strength across the Copenhagen metropolitan area, this would require additional sites supplemented by gap-fillers operating in the same frequency and large transmission powers [27].

A.4 Simulation Results

The Viasat-TDC test has demonstrated the technical feasibility of a broadcast DVB-H mobile multimedia system. The system has been implemented end-to-end successfully. The signal level was tested in different modes – on the train, in the car, as a pedestrian, and inside buildings. Due to the limitations[99], the signal level has been evaluated from a picture quality point of view. According to Per Fly Hansen from TDC, the results of the pilot were very positive. The mobile TV service quality was attractive where the coverage level was high. The outdoor coverage achieved in the Copenhagen area that is close to the transmitter tower was excellent. I personally took part of this test and I can say that it was a satisfying experience to watch TV on the move, where the coverage is high. However, the indoor coverage was acceptable in certain areas where the coverage was 90%, but the quality is compromised below that. Generally, the overall real life results seem to reflect the simulation results to some extent.

A.5 Impressive Danish test of mobile TV of the future

It is top quality and ideal for use in situations with breaks and waiting time. This is the main conclusion of the mobile TV test recently conducted by Viasat and TDC.

Over the summer, twenty people located in Copenhagen tested mobile TV with the DVB-H (Digital Video Broadcasting, Handheld) standard, which is expected to become the European standard for the distribution of mobile TV in broadcast quality. The results of the test show that mobile TV via DVB-H far exceeded the test participants' expectations. The quality of sound and picture, in particular, were assessed to be extraordinarily good.

Furthermore, the test participants emphasise that television via mobile phone makes it possible to keep up to date on news, sports, TV series etc., and that it is a good way to kill time, especially on the bus or train. For the test participants, mobile TV primarily represents a supplemental, and thus increased, use of TV due to the mobility. The use of stationary TV is not affected by the access to mobile entertainments.

The goal of the test was to obtain Danish user experience with DVB-H. Both Viasat and TDC have conducted similar tests in other countries, e.g. Switzerland and Sweden, and the companies achieved their primary objectives for the Danish test. Firstly, that the users found television on their mobiles via DVB-H attractive and interesting, and

[99] The objective was to evaluate the signal level in real life and compare it to the simulation results. However, this was not possible due to the fact that neither DTU nor TDC has provided the necessary tools to achieve this objective.

secondly, that DVB-H meets the technical requirements for the distribution of TV signals in broadcast quality to mobile phones.

Italy and Finland are both far ahead with DVB-H, and several of the other EU countries are well underway. Moreover, the European Commission has clearly indicated that DVB-H should be the pan-European standard. But whether it will be a requirement of the gatekeeper in the future Danish digital television network that mobile TV be offered In the DVB-H standard remains undecided.

About the DVB-H test

- DVB-H requires that the TV signal is broadcast, meaning that many users can receive the signal at the same time in very high picture quality. TDC already offers TV on the mobile phone as streaming via the 3G network.
- The test signal was transmitted from Lynetten in Copenhagen for approximately one month (from late June to late July). The range of the signal covered an area that included: Hellerup, Emdrup, Brønshøj, Valby and Christianshavn.
- All twenty test pilots were given a Nokia N92 mobile phone, which they were to use with their own SIM cards. This gave them free access to DVB-H TV with the following channels: DR1, TV 2, TV 2 News, TV 2 Sport, TV 3, TV 3+ and MTV.
- DR, TV 2, MTV, Nokia and Broadcast Service Danmark were also involved in the test.

Quotes from test participants about DVB-H

- "At a birthday party in our courtyard at home, the afternoon was saved for some of our guests because we could watch 'The Chicken' break away from the pack in the Tour de France.''
- "It's great to be able to take your TV to bed with you."
- "Really useful when you're on a walk with the baby. You just lay the phone Down on the pram

A.6 DVB-H coverage planning and test-system

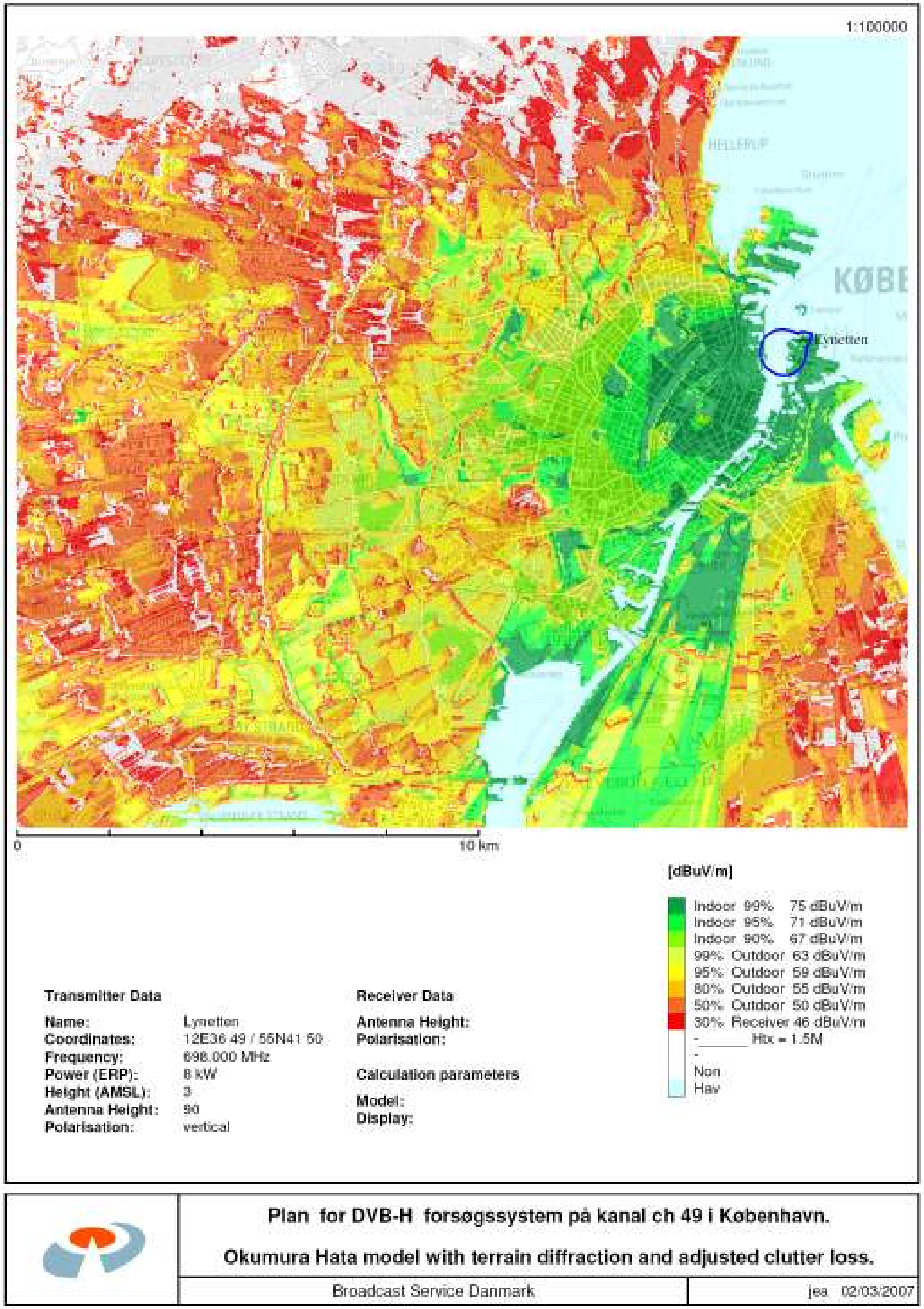

Figure A.4 DVB-H coverage area probability planning in Copenhagen

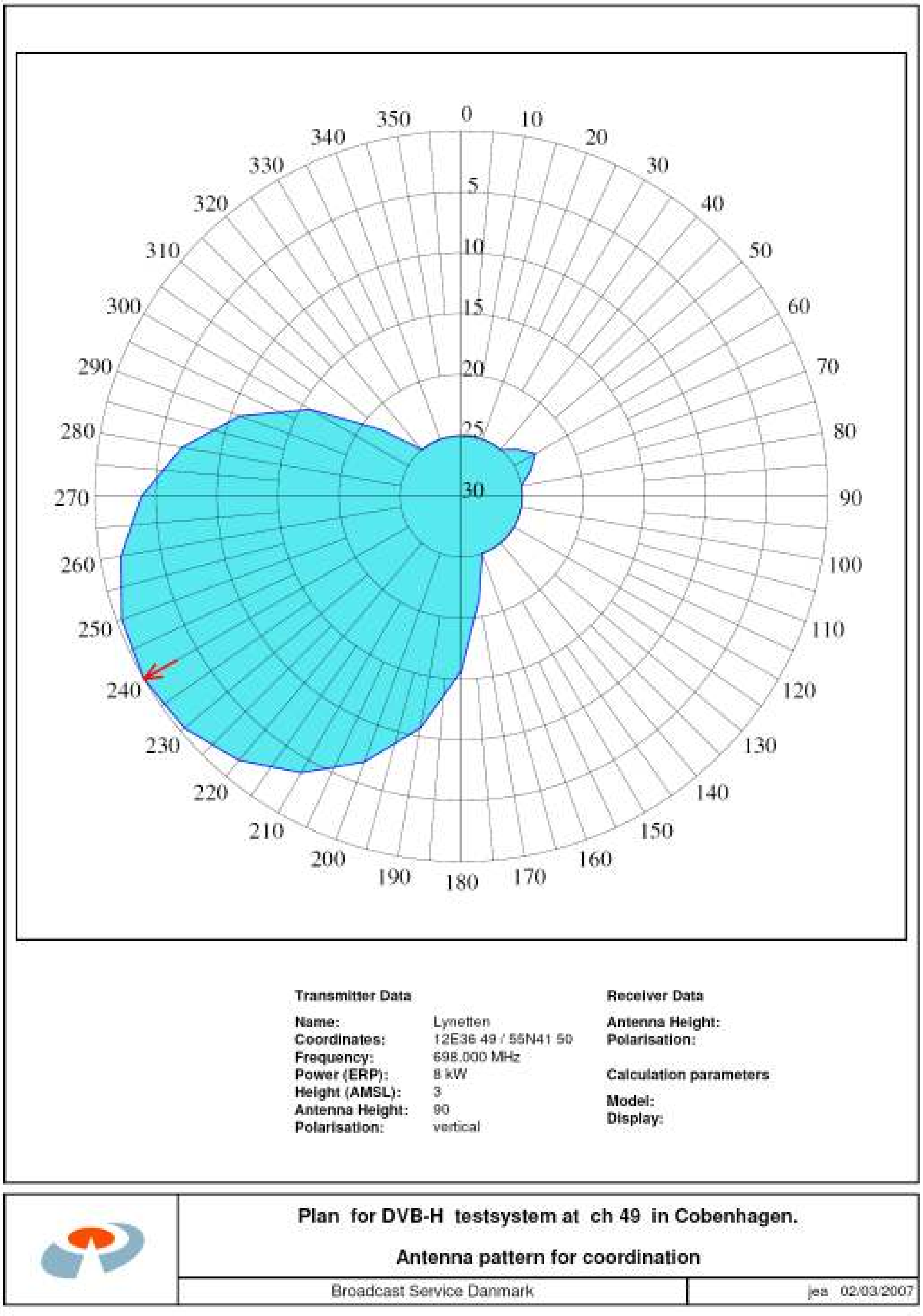

Figure A.5 DVB-H test-system

B. DVB-H PROTOCOL STACK

DVB-H has been designed to serve different applications and file formats including audio, video as well as file transfer such as HTML and XML files. These applications are carried out over the IP data cast layer. This layer serves the purpose of delivering data content in the form of IP packets through the DVB-H physical layer. The DVB-H physical layer serves the purpose of providing MPEG-2 transport and COFDM transmission in the same way the DVB-T physical layer does. The only difference is that DVB-H uses an extra mode, which is 4K in COFDM. This mode (4K) is described in section 4.5.4.

In the IP encapsulator, the audio and video contents are encoded using the highly recommended coding format H.264/AVC. This is done before they are delivered in the form of IP packets using the UDP/IP stack at the network layer [25]. DVB-H also uses the file transfer application FLUTE to deliver data audio, video clips and ESG[100] in an unidirectional manner. Figure B.1 shows an overview of the DVB-H protocol stack.

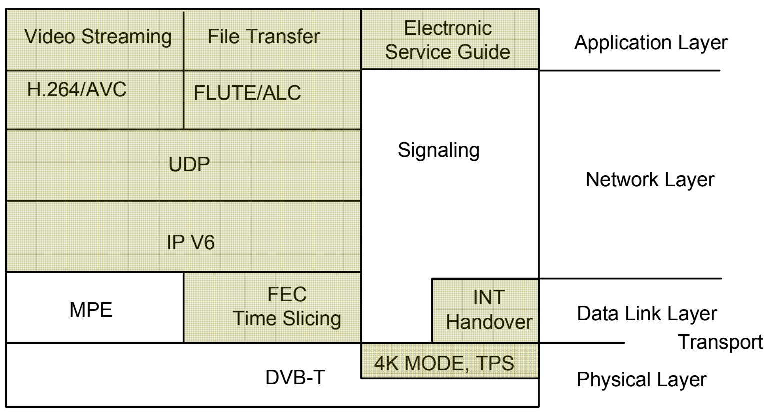

Figure B.1 Overview of the DVB-H Protocol Stack [3]

To provide scalability, the IP data casting is defined based on IPV6. This will support a rapid increase in the number of IP addresses of the mobile handsets, also enhancing security and QoS features. Furthermore, DVB-H introduced several key changes, both in the link and physical layer of the DVB-T system. The reason is to provide an optimal level of service quality for the mobile users.

C. SECURITY

"*There will not be continued growth in digital television revenues without increase and more sophisticated security and access*" [36] says Alan Griffiths managing partner of e-communications.

The content sharing in the early days of the Internet has resulted in revenue loss to rights holders. Consequently, serious measures have been approached in digital rights management (DRM), so that the rights holders can receive their dues. In DVB-H broadcast, the content can be received by million of users, so it may be necessary to

[100] Electronic Service Guide is a key factor for the mobile subscribers to access IP data cast services. This service guide is offered by the IPDC service provider and is broadcasted along with the content. It contains information on the available services such as the services or content that are available and their diffusion time.

encrypt the digital content before transmission of the content, so that only authorized users with a license (decryption) key will be able to decrypt and view the content.

The DVB-H uses DRM for access rights and data encryption. DRM enables content owners to decide which rights should be given to content users and provides service protection by ensuring that only authorized mobile users in the DVB-H network can access TV services. This however requires the mobile user's handset to support Public-Key Infrastructure (PKI) authentication [6]. The PKI on the other hand allows secure content transmission by enabling the content to be encrypted prior to transmission to the mobile user.

In a cellular and broadcast network convergence, the authentication can be handled by the cellular operator, while the DVB-H broadcast operator provides TV content delivery to mobile devices. The cellular operator also provides interactive services and service charging for ordered content. Figure C.1 depicts DVB-H content delivery in an interactive mobile network.

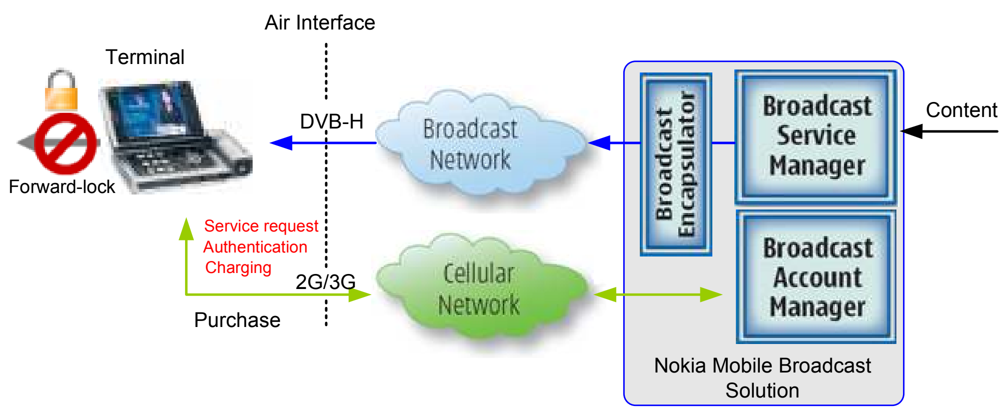

Figure C.1 DVB-H content delivery in interactive mobile network[101]

Additionally, many DRM systems have been proposed such as *forward-lock,* which is a DRM capability built inside the phone to prevent the downloaded content to be copied or forwarded to another phone [52]. There is no encryption or decryption associated with the delivery of the content as the latter is delivered unencrypted to the mobile device. The mobile device is then allowed to display and play the content but not forward it to another mobile device. This security mechanism is another way to enforce the content owners' security and rights protection.

D. FEC SECTION

The FEC frame consists of up to 1024 rows. Each row consists of 191 columns of IP data and 64 columns of FEC data in form of parity bytes. Since every column represents a byte, the frame will consist of 191 bytes of IP data. Adding the forward error correction will result in 255 bytes. Thus, if 1024 rows are used in the frame, this will result in 191 Kbytes of IP or 255 Kbytes of total transmitted data. This is equivalent to 1.528 Mbits of IP data and 2.040 Mbits of transmitted data. Figure D.1 below depicts the frame structure of MPE-FEC.

[101] The picture has been taken from [53] and been modified to illustrate the extra security feature in the mobile handset.

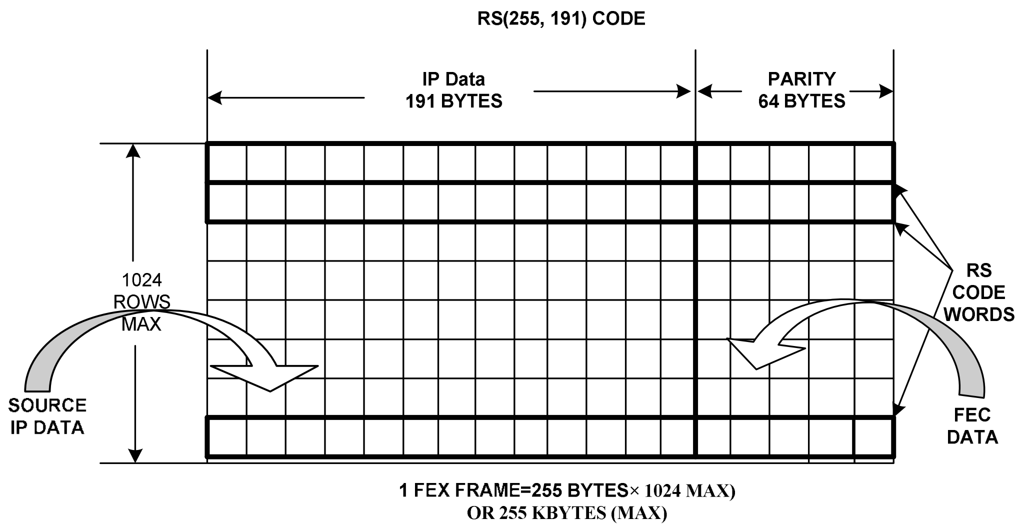

Figure D.1 MPE-FEC Frame Structure [3]

E. SUPPLEMENTARY FIGURES

Thesis Plan				
15-mar-07				
Week numbers:	9	10	11	12
Week start date:	01-mar	05-mar	12-mar	19-mar
Week end date:	02-mar-07	09-mar-07	16-mar-07	23-mar-07
Task to accomplish	Problem formumation	Problem formumation	Thesis structure	Table of content
Week numbers:	13	14	15	16
Week start date:	26-mar	02-apr	09-apr	16-apr
Week end date:	30-mar-07	06-apr-07	13-apr-07	20-apr-07
Task to accomplish	Documentation	Documentation	Technical aspects of DVB-H	Technical aspects of DVB-H
Week numbers:	17	18	19	20
Week start date:	23-apr	30-apr	07-maj	14-maj
Week end date:	27-apr-07	04-maj-07	11-maj	18-maj
Task to accomplish	Economic aspects of DVB-H	Economic aspects of DVB-H	DVB-H Netwrok Planning	Vaccation
Week numbers:	21	22	23	24
Week start date:	21-maj	28-maj	04-jun	11-jun
Week end date:	25-maj	01-jun	08-jun	16-jun
Task to accomplish	Econnomic of unicat	Economic of brodcast	Economic of brodcast	Economic of monile TV using 3G
Week numbers:	25	26	27	28
Week start date:	18-jun	25-jun	02-jul	09-jul
Week end date:	22-jun	29-jun	06-jul	13-jul
Task to accomplish	Economic of monile TV using	DVB-H business model	DVB-H business model	DVB-H network investement
Week numbers:	29	30	30	30
Week start date:	16-jul	23-jul	30-jul	06-aug
Week end date:	20-jul	27-jul	03-aug	10-aug
Task to accomplish	DVB-H network investement	DVB-H network investement	DVB-H network investement	Future market
Week numbers:	30	30	30	30
Week start date:	13-aug	20-aug	27-aug	03-sep
Week end date:	17-aug	24-aug	31-aug	04-sep
Task to accomplish	Evaluation of results	Conclusion and Future work	Expected thesis delivery	Thesis delivery

E.1 Thesis Plan

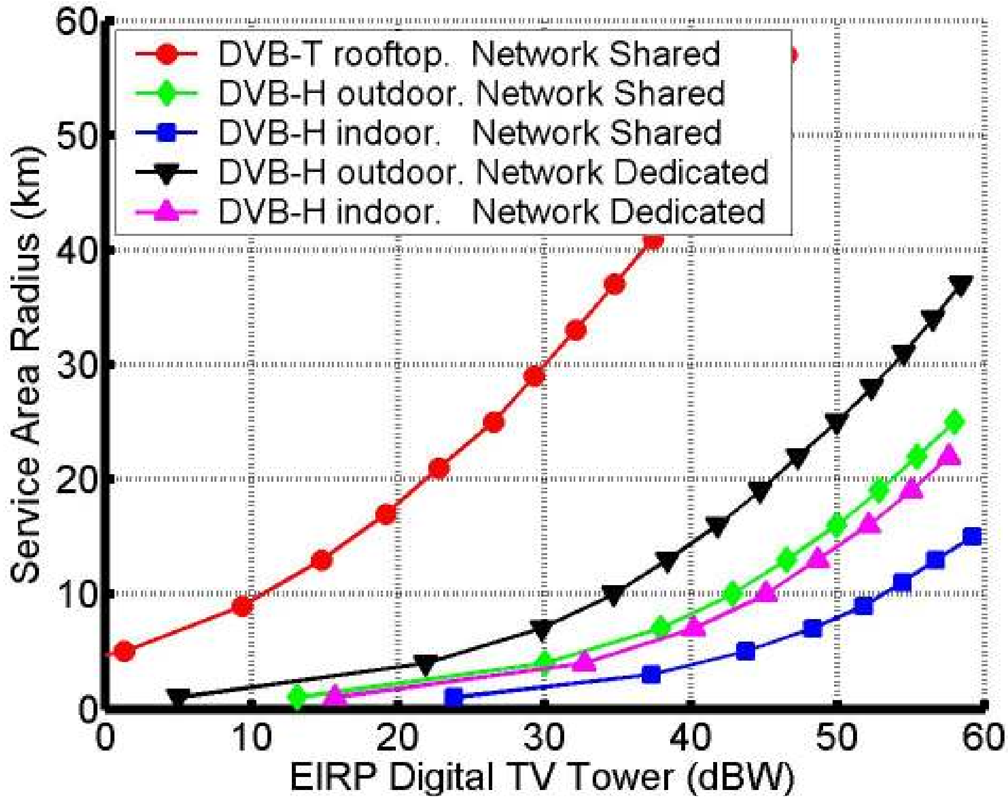

Figure E.2 Coverage Area Radius vs. Power from the TV Tower [28]

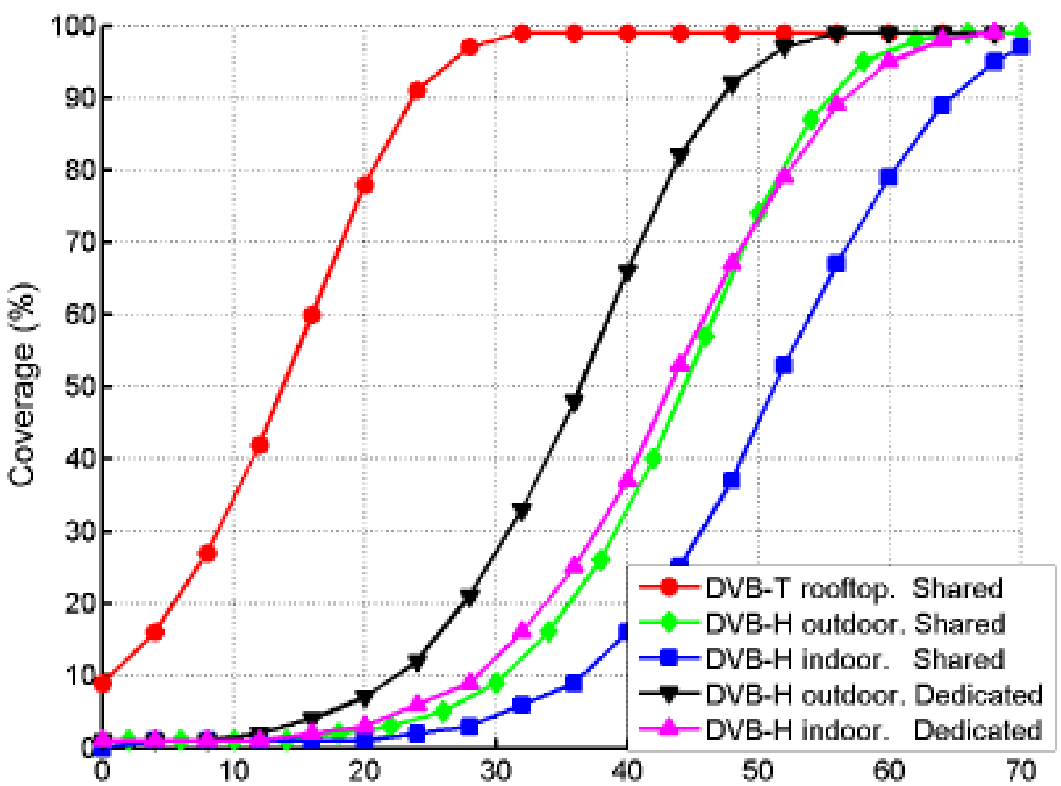

Figure E.3 Area coverage vs. EIRP for a 150m height TV tower. Service area radius is 25 km [48].

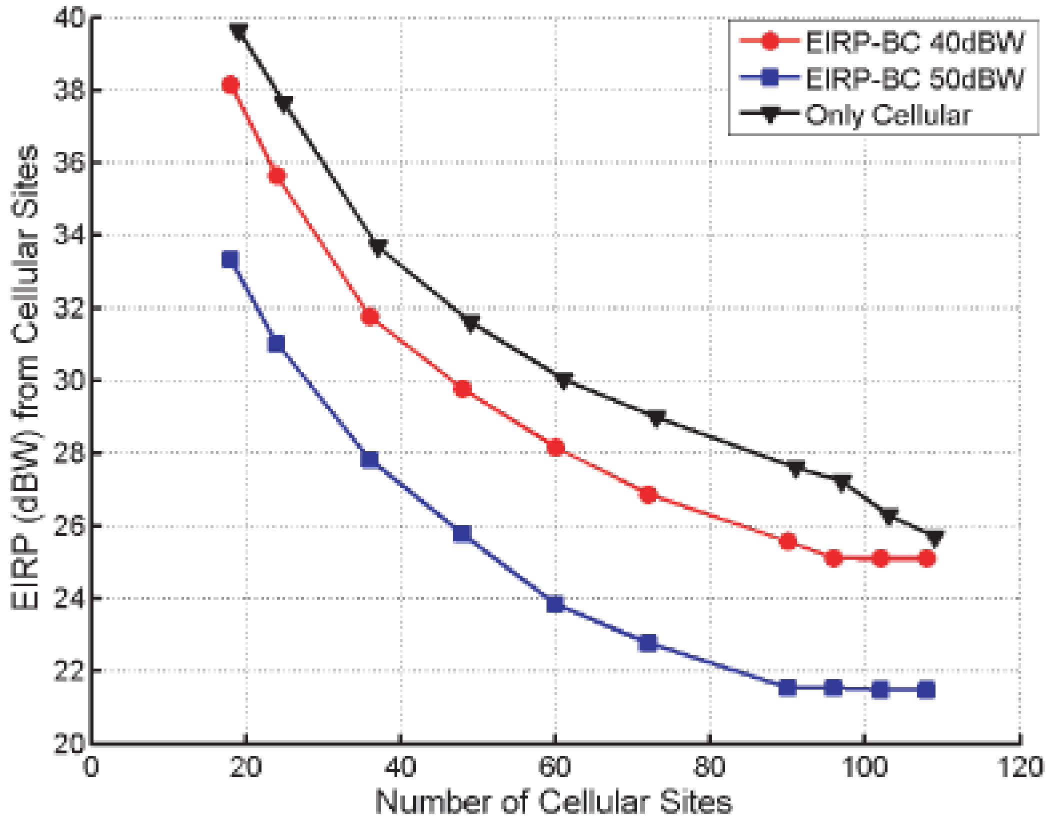

Figure E.4 Required EIRP at a cellular site as a function of the number of sites employed. Cell radius is 2.5 km. Service area radius is 25 km (around broadcasting tower). Target coverage is 95% for indoor handheld devices [48]

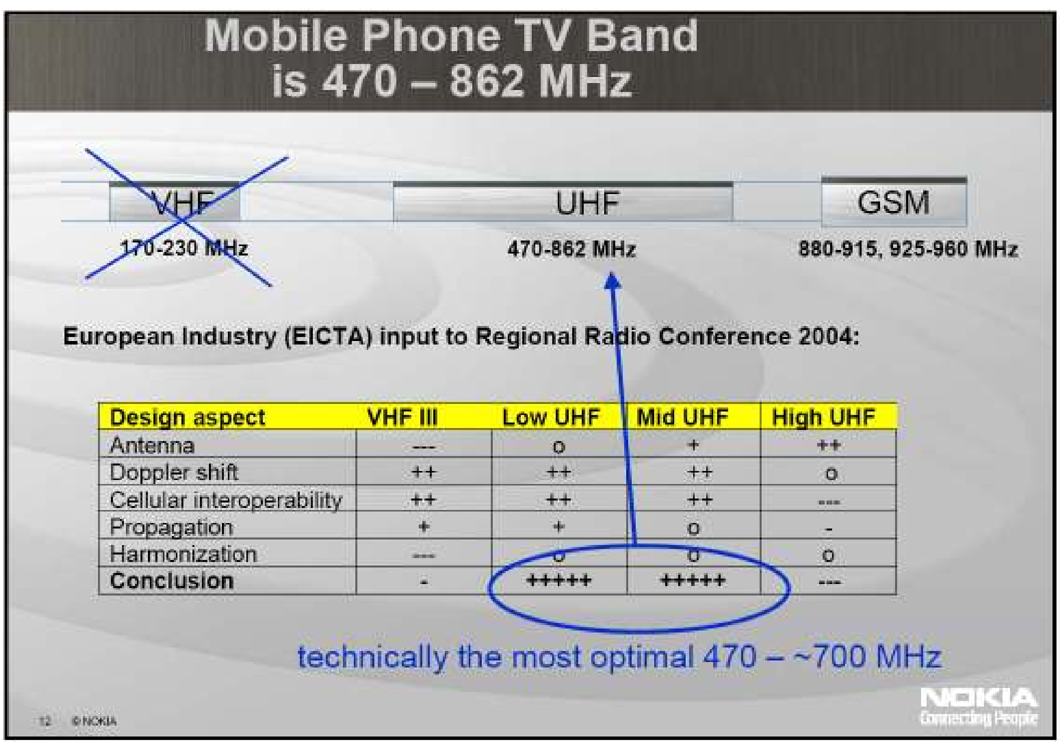

Figure E.5 Mobile Phone TV Band is 470 – 862 MHz

	2015	2015	2030	2050
0-5 years	367 083	367 083	394 151	374 425
6-16 years	727 076	727 076	693 675	703 931
17-24 years	571 003	571 003	526 756	544 829
25-64 years	2 844 012	2 844 012	2 746 014	2 619 682
65 years and over	1 050 659	1 050 659	1 356 423	1 440 735

Figure E.6 Population projections 2007 for the country by age and time
(Statistical Yearbook 2006)