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# IP Datacast and the Cost Effectiveness of its File Repair Mechanism

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## 1. Introduction

Internet protocol datacast (IPDC) (ETSI, 2006a) is a framework for the distribution of digital data services to wireless, mobile handsets via a broadcast infrastructure based on digital video broadcasting for handhelds (DVB-H). The technical extensions of DVB-H (ETSI, 2004; Faria et al., 2006) to the widely used terrestrial DVB transmission system called DVB-T (ETSI, 2009a; Reimers, 2005) allow for specific requirements of rather small mobile devices, like a smaller screen size compared to television sets, or their dependency on accumulators for electricity and therefore their special need for low power consumption. As a broadcasting infrastructure does not automatically offer the possibility of data transmission in the "upstream" path from a mobile device to the sender, in the context of IPDC this sole one-way system is enriched with upstream paths using cellular networks or wireless local area networks (WLAN) – two types of networks which are typically used by mobile devices. Using these upstream paths for interactivity or signalling purposes, handsets are given the possibility to inform the sender about lost data segments allowing it to retransmit portions of data already sent.

This chapter will give an introduction into the digital video broadcasting (DVB) technology, especially into the DVB transmission system useful for mobile devices called DVB-H. It will describe the architecture of IP datacast, which is based on DVB-H, and the protocols used by this technology. One means of using IPDC is the broadcasting of binary data to a number of receivers using IP multicast protocols. In order to achieve correct reception of all of the sent binary data, a signalling mechanism has been specified, which enables receivers to inform the sender about lost or irreparable data fragments. This so-called file repair mechanism allows the setting of different parameters which affect the amount of data which can be corrected at the receiver and therefore have impact on the retransmission costs. The main topics of the research presented in this chapter are studies on the parameterization of the IPDC file repair mechanism and the effects of retransmissions on financial repair costs. In order to accomplish these studies, a simulation model has been designed and implemented which simulates an IP datacast network including a state-of-the-art error model for the wireless transmission channel and a versatilely parametrizable implementation of the file repair mechanism.

Source: Digital Video, Book edited by: Floriano De Rango,
ISBN 978-953-7619-70-1, pp. 500, February 2010, INTECH, Croatia, downloaded from SCIYO.COM

## 2. Digital video broadcasting

The systems, procedures and protocols necessary for the distribution of digital television and other media services are contained in the general term "digital video broadcasting". The specifications describing all of these components are worked out by the Digital Video Broadcasting Project, which is a consortium of over 270 broadcasting network operators, equipment manufacturers, regulatory bodies and others (DVB Project Office, 2009a). The predecessor of the DVB Project was the European Launching Group (ELG), which constituted in 1991 with the goal to introduce an open and interoperable digital television system in Europe. The DVB Project consists of several organizational parts. One of them is the Commercial Module, which is responsible for determining market requirements. Another one, the Technical Module, drafts the technical specifications necessary for implementing these requirements. Once a specification is finished by the corresponding working groups within the Technical Module, it has to be approved by the Steering Board. If this approval is successful, the specification is handed over to the European Telecommunications Standards Institute (ETSI) for formal standardisation. Although the work on DVB started in Europe, it has become a very successful solution worldwide, with more than 230 million DVB receivers (DVB Project Office, 2009a).

### 2.1 DVB transmission systems

The set of specifications of the DVB Project contains a multitude of technical solutions for the distribution of DVB services, some of them are shortly described in the following paragraphs.

DVB-S/DVB-S2

DVB-Satellite (DVB-S) and DVB-Satellite 2nd generation (DVB-S2) are digital satellite transmission systems. The first digital satellite TV services using DVB-S started in 1994. Currently, more than 100 million receivers are deployed conforming to this technology (DVB Project Office, 2008a). Due to the progress in many related technical areas like channel coding, modulation, error correction and media compression, the second generation digital satellite system DVB-S2 was published in 2005, taking advantages of these improvements thus creating the basis for commercially viable high-definition television (HDTV) services. As it is expected that both systems will coexist for several years, DVB-S2 was created with backwards compatibility in mind. Through the use of hierarchical modulation, legacy DVB-S receivers will continue to operate while additional capacity and services will be delivered to the second generation receivers (DVB Project Office, 2008a).

DVB-C/DVB-C2

DVB-Cable (DVB-C) and DVB-Cable 2nd generation (DVB-C2) are the first and second generation digital cable transmission systems specified by the DVB Project. Generally, the two systems make use of the wired infrastructure of cable TV providers, which mainly consists of hybrid fibre-coaxial (HFC) systems. DVB-C was published by ETSI in 1994 and the second generation DVB-C2 is expected to be published in 2009. Comparable to the satellite system, DVB-C2 among other things makes use of improved error correction and modulation schemes. As an example, data rates of up to about 80 Mbps per 8 MHz channel can be achieved when using 4096-quadrature amplitude modulation (DVB Project Office, 2009b).

DVB-T/DVB-T2

Concerning the terrestrial broadcasting of digital TV services, the corresponding first and second generation transmission systems developed by the DVB Project are called DVB-Terrestrial (DVB-T) and DVB-Terrestrial 2nd generation (DVB-T2). The first version of the specifications was published in 1997, and the first TV service using DVB-T was launched in the United Kingdom in 1998. In the meantime, more than 90 million receivers have been sold in more than 35 countries (DVB Project Office, 2009c). The second generation system provides improved modulation and error correction techniques and is expected to be published in the second quarter of 2009 (DVB Project Office, 2009d).

DVB-H

The approach of analogue switch-off (ASO) in many countries worldwide leads to the installation of digital terrestrial television (DTT) infrastructures. In Europe, as in many other parts of the world like in Australia, Asia and South America, this DTT infrastructure is based on DVB-T, mainly focused on fixed receivers. To make this system also available for mobile end systems, extensions have been specified under the designation DVB-Handheld (DVB-H). These typically small handheld devices have special characteristics like comparatively small screen sizes and special requirements like low power consumption. To meet these features and needs, appropriate extensions to the DVB-T specifications were needed (see section 2.2). Concerning DVB-H services, the main focus was on video streaming including mobile TV and file downloads (DVB Project Office, 2009e). A huge number of DVB-H trials have taken place all over the world, and full service has been launched in 14 countries (DVB Project, 2009a).

DVB-IPDC

A set of necessary components has to be built on top of the broadcasting infrastructure in order to make mobile TV services successful. Such components include e.g. an electronic service guide (ESG) for the announcement of the services offered or a framework for the purchase of specific services. These complementary building blocks have been specified within DVB-IP datacast (DVB-IPDC), which is intended to work with the DVB-H physical layer (DVB Project Office, 2008b). As a general set of system layer specifications, DVB-IPDC can be implemented for any other Internet protocol (IP) (Postel, 1981) capable system. A special property of mobile TV systems is the expected availability of an additional bidirectional connection based on 3G cellular or WLAN networks. This provides the possibility of individualization of certain services.

DVB-SH

To extend the coverage area of DVB-H based mobile TV systems, the hybrid satellite/terrestrial DVB-Satellite services to handheld (DVB-SH) transmission system has been specified. The main distribution is achieved by using satellite transmission, with terrestrial gap fillers servicing areas with poor satellite reception characteristics. DVB-SH is an extension to the DVB-H infrastructure and can be used as a transmission layer for IPDC based services. In April 2009, a satellite for the construction of a DVB-SH network targeting several European markets was launched (DVB Project Office, 2009f).

### 2.2 Digital video broadcasting – handhelds

As DVB-H is generally based on DVB-T, this section first of all describes the transmission system of DVB-T, followed by the extensions that constitute DVB-H.

DVB-T Transmission System

The basic transmission system that is used by both DVB-T and DVB-H was specified by the Moving Picture Experts Group (MPEG). It is called the MPEG-2 transport system and was published by the International Organisation for Standardisation (ISO) as an international standard (ISO/IEC, 2007). The basic building blocks of this system are shown in figure 1. The media encoder applies specific operations on the audio and video streams to reduce the necessary capacity for transmitting them. These are in general lossy encoders based on MPEG specifications. For example, using MPEG-2 video encoding, a standard definition television (SDTV) video signal can be compressed to about 4 – 6 Mbps instead of 166 Mbps without compression (Reimers, 2005). The compressed media streams are called elementary streams (ES) and are input to the packetizer, which divides each stream into packets of variable length up to 64 kB, depending on the content of the stream. A compressed media stream packetized in this way is called packetized elementary stream (PES). As these relatively large PES data segments are not suitable for broadcasting a number of audio and video programs within one data signal, they are further broken down into smaller data chunks called TS packets by the transport stream (TS) multiplexer. Each TS packet has a fixed length of 188 bytes consisting of a 4 bytes header and 184 bytes payload, which carries the particular parts of the PES packets. A single service program can consist of multiple audio, video and other data streams represented as streams of TS packets, and the combination of several TV programs plus additional signalling data is multiplexed by the TS multiplexer into a complete data stream called MPEG-2 transport stream.

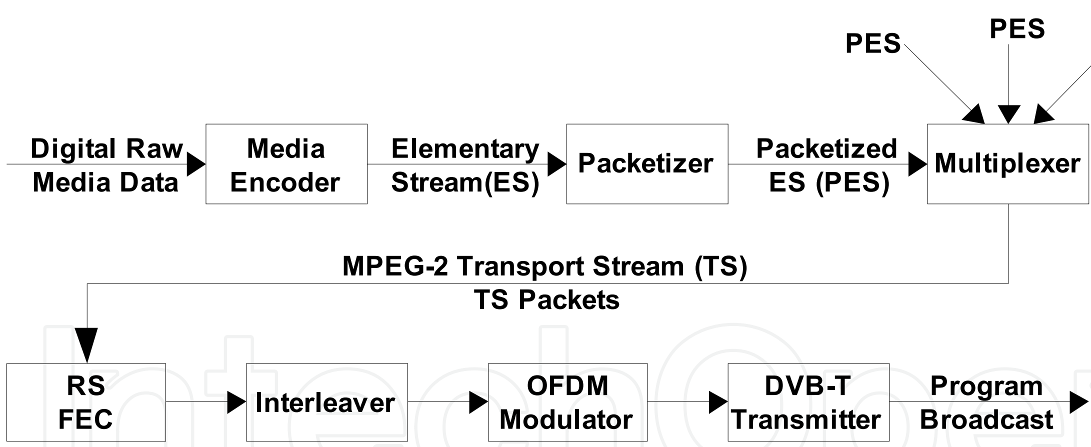


Fig. 1. Basic building blocks of the MPEG-2 transport system.

In the course of media encoding and compression, redundancy is removed from a media stream and the resulting data stream is rather fragile with respect to disruptions during the broadcast. Therefore, some redundancy has to be added systematically to be able to react on transmission errors and correct the received data stream. In DVB, primary error protection is achieved by using the Reed-Solomon (RS) forward error correction (FEC) block code. For each 188 bytes long TS packet, 16 bytes of checksum (or parity data) computed by the used RS code is added, resulting in a total length of 204 bytes. This FEC code allows the repairing of up to 8 bytes per TS packet. Packets containing more than 8 errors can not be corrected but still reliably detected and flagged as erroneous (Reimers, 2005).

Concerning DVB-T, the resulting stream of error protected TS packets is interleaved to counteract error bursts, and in the convolutional encoder additional error protection is added. After a further subdivision and interleaving of the data stream depending on the type of modulation, which can be quadrature phase-shift keying (QPSK), 16-quadrature amplitude modulation (QAM), or 64-QAM, the resulting signal is passed on to the orthogonal frequency-division multiplexing (OFDM) modulator. DVB-T supports the two OFDM transmission modes 2K and 8K, which make use of 2048 and 8192 subcarriers respectively mapped on a channel with a bandwidth of 8, 7 or 6 MHz. While the 2K mode provides larger subcarrier spacing (about 4 kHz compared to about 1 kHz using 8K mode), the symbol length is shorter (about 250 µs versus 1 ms). For mobile devices, the 2K mode is less susceptible to the Doppler effects due to its larger carrier spacing. On the other hand, the 8K mode allows greater transmitter spacing because of longer guard intervals and is therefore the preferable mode for single frequency networks (SFN). More specific technical details of the modulation and coding techniques of DVB-T can be found in (Reimers, 2005).

Extensions of DVB-T

DVB-H was specified as a set of extensions to DVB-T focussing on small, mobile receivers. Due to limited energy supply and more difficult signal reception conditions, two main extensions to DVB-T were defined: an access scheme called time slicing and an additional FEC mechanism. With time slicing, which is mandatory in DVB-H, the DVB-H data streams are not sent continuously but in bursts. This allows the receiver to power off between these bursts, thus saving energy. Depending on the bit rate of a DVB-H stream, these power savings can be up to about 90% (ETSI, 2009b). The second extension, which is an optional extension, is called multiprotocol encapsulation forward error correction (MPE-FEC) and is described in more detail in the next paragraph. Both extensions work perfectly upon the existing DVB-T physical layer and therefore DVB-H is totally backwards compatible to DVB-T (Faria et al., 2006). Nonetheless, some extensions to the physical layer were specified as well, among these the new 4K transmission mode, which is a complement to the existing 2K and 8K modes and is a compromise between mobility and SFN cell size.

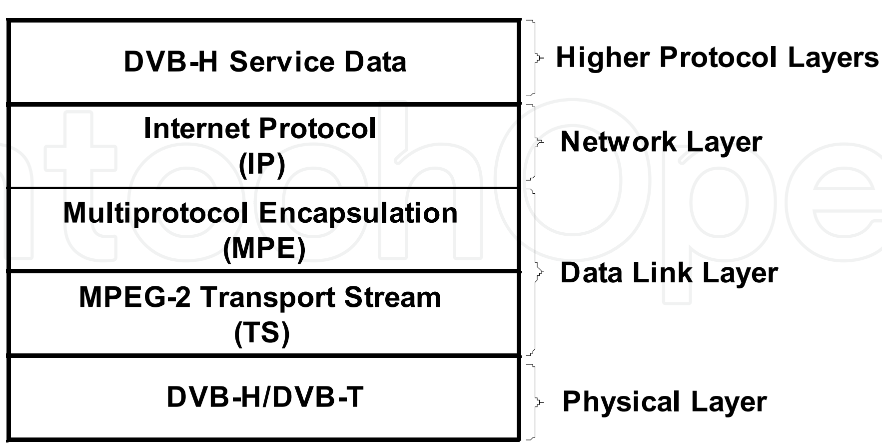


Fig. 2. DVB-H protocol stack adapted from (ETSI, 2009b).

All DVB-H payloads are carried within IP packets or other network layer protocol data units which are further encapsulated using multiprotocol encapsulation (MPE). Each IP packet is encapsulated into one MPE section and a stream of MPE sections build an elementary stream, which is further processed as described above and which is therefore finally mapped to a stream of TS packets that can be multiplexed into an MPEG-2 transport stream (see figure 2).

Multiprotocol Encapsulation Forward Error Correction

All DVB-H user data is transported in IP packets, each of them encapsulated in one MPE section. Each MPE section consists of a 12 bytes header, an IP packet as payload (max. 4080 bytes) and 4 bytes checksum. To further protect the IP data, an additional FEC code may be applied on the data. By using multiprotocol encapsulation forward error correction (MPE-FEC), some parity data is calculated and transmitted to the receivers which in turn can use this redundancy to correct corrupt data segments. The FEC code used by MPE-FEC is the Reed-Solomon (RS) block code RS(255,191). For a more detailed explanation of this FEC code see (ETSI, 2009b) and (Reimers, 2005).
An MPE-FEC frame is a logical data structure containing two data tables: the application data table (ADT) which consists of 191 columns and the Reed-Solomon (RS) data table which consists of 64 columns containing the parity bytes calculated by the FEC code (see figure 3). The number of lines can be 256, 512, 768 or 1024. As each cell in the two tables contains one byte, the size of a MPE-FEC frame either is 47.75 kB, 95.5 kB, 143.25 kB, or 191 kB.

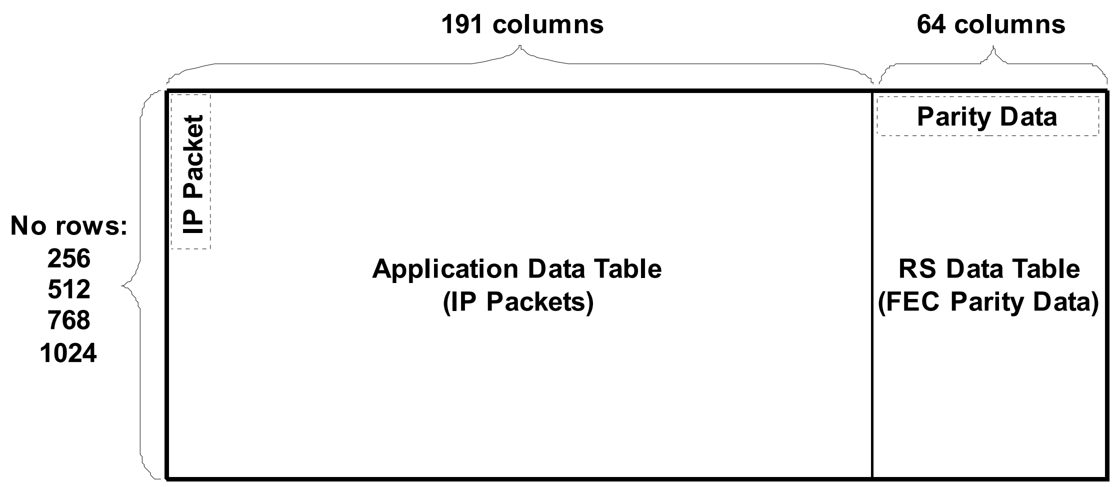


Fig. 3. MPE-FEC frame.

The IP packets plus optional padding are inserted into the ADT column by column. The RS code is applied on this data to calculate 64 parity bytes per ADT line, contained in the RS data table of the MPE-FEC frame. Concerning the data transmission, each IP packet of the MPE-FEC frame is transported within an MPE section, followed by the parity data. Each RS data table column is transported within an MPE-FEC section. The corresponding protocol stack is shown in figure 4.

### 2.3 IP datacast

IP datacast is a set of specifications for mobile TV systems based on IP capable systems. IPDC is specifically defined as a complement to DVB-H transmission systems, in this context called DVB-IPDC or IPDC over DVB-H. In the following, IPDC is taken short for IPDC over DVB-H. The basic building blocks of IPDC, which are described in this section, generally define how any types of digital content and services are described, delivered and protected.

Building Blocks of IPDC

An inherent part of the IPDC architecture is the possible combination of a unidirectional broadcast path realized by DVB-H and a bidirectional unicast interactivity path realized by e.g. cellular or WLAN data connections. In this way, an IPDC receiver, which is mainly built into a mobile phone, cannot only receive broadcast services but can make use of individual services or signalling through the interactivity path.

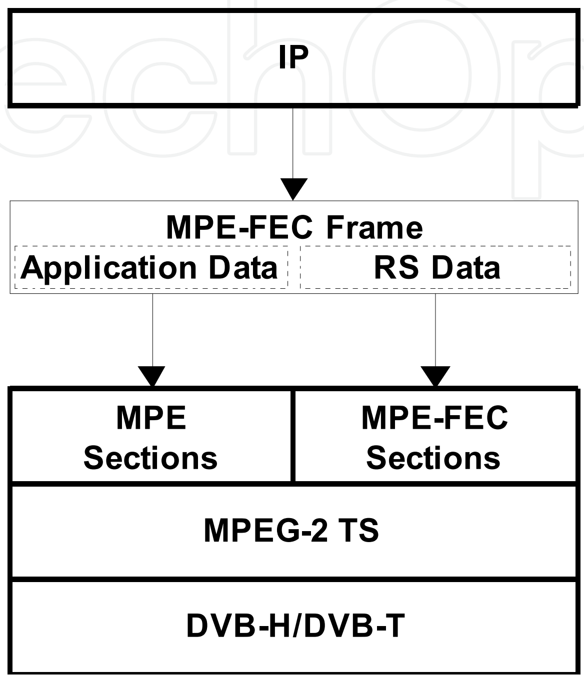


Fig. 4. DVB-H protocol stack using MPE-FEC.

The most important building blocks of IPDC are (DVB Project Office, 2008b):

- Electronic service guide (ESG): the ESG describes the services offered by an IPDC system as structured information, based on the extensible markup language (XML).
- Service purchase and protection (SPP): the SPP framework provides protocols and mechanisms for rights management and the encryption of digital content.
- Content delivery protocols (CDP): CDP is the set of protocols used by IPDC for media streaming and file delivery services.

Content Delivery Protocols

The set of protocols used for the delivery of the various mobile TV services, including media streaming and general file delivery, is called content delivery protocols (CDP) and is specified in (DVB Project, 2009b). As shown in figure 5, IPDC uses a complex stack of protocols, which can be divided in two subgroups: IP multicast based protocols for unidirectional delivery and IP unicast based protocols for interactive services, service additions or additional signalling purposes. Audio and video real-time media streams are delivered using the real-time transport protocol (RTP) and the RTP control protocol (RTCP) (Schulzrinne et al., 2003). The delivery of arbitrary binary data objects (like applications, ring tones and the like) is conducted via the file delivery over unidirectional transport (FLUTE) protocol (Paila et al., 2004), which is based on asynchronous layered coding (ALC), one of the Internet Engineering Task Force's (IETF) base protocols for massively scalable reliable multicast distribution (Luby et al., 2002). The number and types of binary data objects to be distributed within a FLUTE session as well as other metadata are described by the XML-based file delivery table (FDT), which itself is distributed using FLUTE. Summing up, the most important protocol stacks are: RTP/UDP/IP multicast for real-time streaming of audio and video, FLUTE/ALC/UDP/IP multicast for the distribution of binary objects and HTTP/TCP/IP unicast for interactivity services.

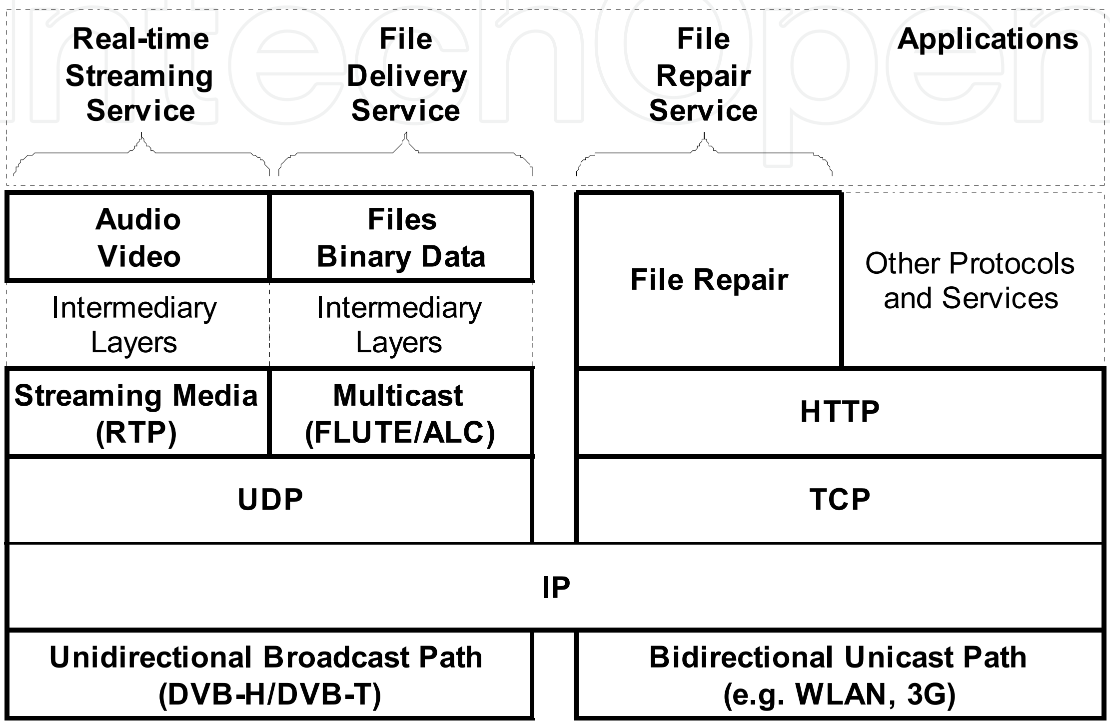


Fig. 5. IPDC content delivery protocols.

Blocking and Encapsulation

For the delivery of binary data objects using FLUTE/ALC/UDP/IP multicast, the procedure for splitting and encapsulating a binary data object for transmission via an IPDC/DVB-H system is basically as follows (ETSI, 2004; ETSI, 2006b). First, the binary object is split into source blocks and encoding symbols by a blocking algorithm as shown in figure 6. The algorithm used depends on the FEC mechanism used at the application layer. For the research done within this work (see section 4), no special application layer FEC (AL-FEC) mechanism was used[1]. Therefore, the binary object is simply split into several source blocks, with each source block consisting of several encoding symbols. The number of encoding symbols per block depends on the chosen encoding symbol size. Next, each symbol produced by the blocking algorithm is encapsulated in a FLUTE/UDP/IP packet and handed over to the MPE and MPEG-2 TS layers. Finally, if additional MPE-FEC is enabled, the procedures described in section 2.2 are applied.

[1] More specifically, this scheme is called the “compact no-code FEC scheme” or “null-FEC” (Watson, 2009).

## 3. IPDC file repair mechanism

IPDC is a general system for the distribution of arbitrary digital services to as many receivers as are within the coverage area. One specific service is the transmission of binary data objects, such as individual songs, which are to be received error-free. In this context the file repair mechanism, which is part of the IPDC specification, allows for the signalling of transmission errors from individual receivers to the sender. This section describes the technical details and procedures of this mechanism as well as the formulas for the calculation of financial retransmission costs due to multiple transmissions of data segments.

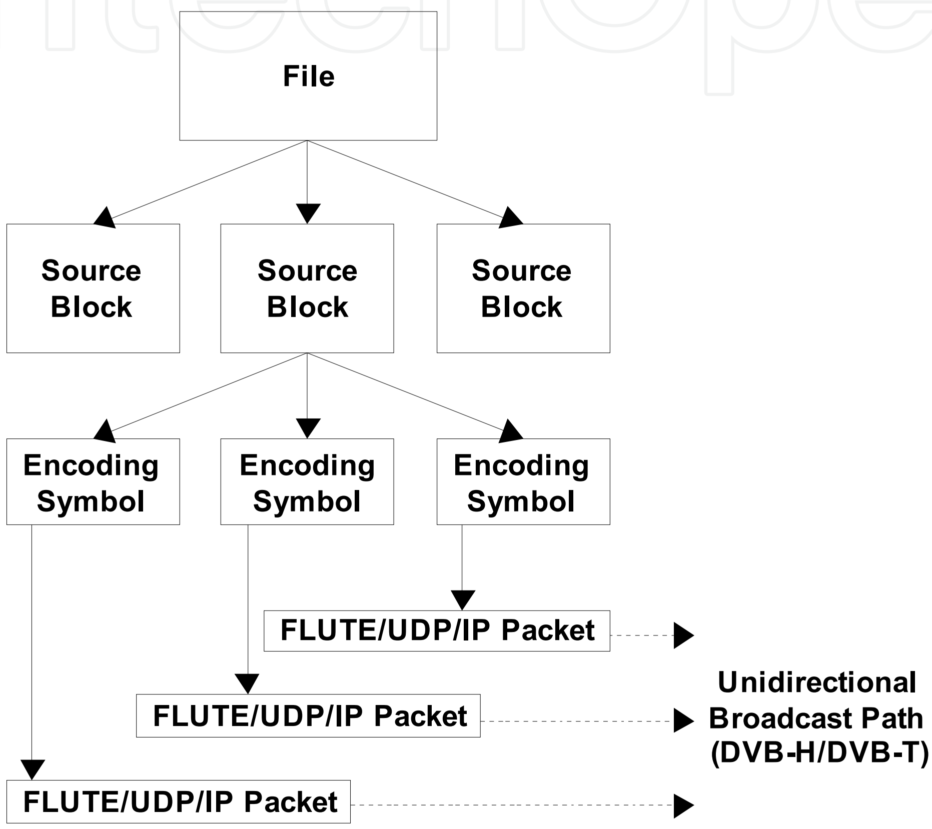


Fig. 6. Blocking and encapsulation.

### 3.1 File repair procedure

The IPDC file repair mechanism, specified in (DVB Project, 2009b), is part of IPDC's so-called associated delivery procedures (ADP). ADPs specify procedures for returning reception information (called "reception reporting procedures") and procedures for carrying out file repairs (called "post-repair procedures"). The former procedures are used for signalling the complete reception of one or more files as well as reporting some statistics about a streaming session. The latter ones are shortly called "file repair mechanism" and their basic purpose is the correction of lost or unrecoverable data segments of a file delivery or FLUTE session. One or more file repair servers accept file repair request messages from the receivers and either answer these requests directly via unicast 3G or WLAN connections (called "point-to-point" or ptp repair) or indirectly by repeating the requested segments via the IPDC/DVB-H broadcast infrastructure (called "point-to-multipoint" or ptm repair), thus delivering the requested repair data to all receivers once again.

The simplified basic procedure of the file repair mechanism is as follows (DVB Project, 2009b). First, a receiver identifies lost or unrecoverably erroneous data fragments or encoding symbols, respectively. Then, after the file transmission is finished, the receiver calculates a random time value called "back-off time". After the back-off time has expired, the receiver sends its file repair requests to the file repair server. Finally, the file repair server replies with a repair response message, which either contains the requested encoding symbols within a ptp repair session or the session description for the ptm repair session.

Concerning the transmission of file repair requests a time window is defined, which begins after the data session has ended. During this window the receivers send their requests at random times, represented by the individual back-off times of the single receivers. All file repair request messages should be transmitted within an HTTP 1.1 GET request (Fielding et al., 1999) to the file repair server via the bidirectional unicast interactivity path. If more than one GET request is necessary, they should be sent without intermediary waiting times. Erroneous data fragments are specified by their source block numbers (SBN) and encoding symbol IDs (ESI). In case of a ptp file repair session, all requested fragments are sent to the receivers via HTTP responses using the interactivity path. In case of a ptm file repair session, all requested fragments are sent via a FLUTE file delivery session based on IPDC/DVB-H.

Example of a File Repair Request Message

In the following example taken from (DVB Project, 2009b) and shown in figure 7, an HTTP GET message to the file repair service "ipdc_file_repair_service" at the server with the fully qualified domain name (FQDN) "www.repairserver.com"[2] is shown. This message represents a file repair request message concerning the binary data object "latest.3gp", which is a downloadable news video file hosted at the server with the FQDN "www.example.com". In this example, the receiver was not able to correctly receive two packets with SBN = 5, ESI = 12 and SBN = 20, ESI = 27. The corresponding MD5 message-digest algorithm (Rivest, 1992) value of the file is used to identify a specific version of the file.

```
GET    /ipdc_file_repair_service?fileURI=www.example.com/news/latest.3gp
       &Content-MD5=ODZiYTU1OTFkZGY2NWY5ODh==
       &SBN=5;ESI=12&SBN=20;ESI=27 HTTP/1.1
```

Fig. 7. Example of an IPDC file repair request message.

Example of a ptp Repair Response Message

In the following example adapted from (DVB Project, 2009c) and shown in figure 8, an HTTP response message from a file repair server is shown. The repair server uses a ptp repair strategy by directly answering the file repair request within the same HTTP session as the request. This HTTP response contains the two requested symbols in two separate groups.

[2] Therefore, the uniform resource locator (URL) of the service is "http://www.repairserver.com/ipdc_file_repair_service".

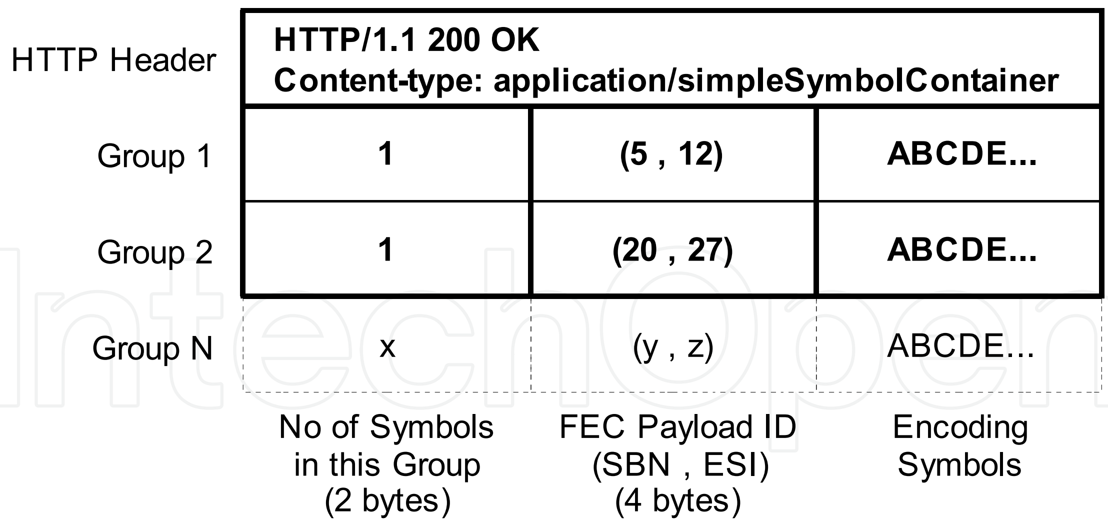


Fig. 8. Example of an IPDC ptp file repair response message.

### 3.2 Cost calculation

Due to the two file repair strategies, different file repair costs may result. Costs may be declared regarding the transmission volume or bytes that result from retransmitted data segments or regarding financial costs that result from transmitting the repair data via the broadcast or interactive paths, respectively. After a file transmission is finished, a file repair server can calculate the expected ptp and ptm repair costs and therefore decide which file repair strategy to choose in order to minimize the repair costs. In case of a ptp repair session, only one repair round is normally sufficient for the receiver to correct all erroneous data segments. For ptm sessions, further rounds could be necessary until all receivers have received complete and error-free data. The cost estimation is done during the time window for file repair requests, which consists of a predefined, fixed value and a random part, the maximum back-off time. At a fraction of the maximum random part of the repair request window, defined by the parameter $\alpha$, the file repair server executes the calculation of the expected costs, based on the repair requests received until this point in time. After the time window for file repair requests has expired, the actual cost of one round of a file repair session can be calculated.

Projected Financial Repair Costs

The projected financial repair costs of a ptp repair session are defined by formula (1), which is specified in (DVB Project, 2009b).
The following parameters are used:

- $c_u$ defines the financial cost of the transmission of a single byte via the used ptp network
- $N_{sym}$ specifies the expected number of requested symbols to repeat
- $s_{sym}$ defines the average size of an encoding symbol in bytes
- $N_{req}$ defines the expected number of repair request messages
- $s_{req}$ specifies the average size of a repair request message in bytes

The expected numbers of repair requests ($N_{req}$) and requested symbols ($N_{sym}$) are calculated by dividing the numbers of repair requests ($n_{req}$) and requested symbols ($n_{sym}$) the repair server accepted until the time of the expected cost calculation (t) by $\alpha$. This calculation is based on the assumption that the repair requests are uniformly randomly distributed over time.

$$C_{ptp(expected)} = c_u \cdot N_{sym} \cdot s_{sym} + c_u \cdot N_{req} \cdot s_{req} \tag{1}$$

Concerning a ptm repair session, it is assumed that the repair server conducts ptp repair until time t and then switches over to ptm repair mode. A service operator should further assume that the ptm repair session contains the whole file to achieve complete reception. Therefore, formula (2) taken from (DVB Project, 2009b) can be used for the calculation of the projected ptm financial repair costs.
The following additional parameters are used:

- $c_m$ defines the cost of the transmission of a single byte via the used ptm network
- S defines the size of the whole file in bytes
- $s_{an}$ specifies the size of a ptm repair session announcement in bytes

$$C_{ptm(expected)} = c_m \cdot (S + s_{an}) + c_u \cdot N_{req} \cdot s_{req} + c_u \cdot n_{sym} \cdot s_{sym} \tag{2}$$

Actual Financial Repair Costs

When the time window for file repair requests has expired, the total cost for one round of a file repair session can simply be calculated by using formulas (1) and (2) and replacing the estimated values for the number of repair requests ($N_{req}$) and the number of requested symbols ($N_{sym}$) therein by their actual values $n_{req}$ and $n_{sym}$ respectively.

## 4. Simulations of the IPDC file repair mechanism

The study shown in this section deals with a simulation framework developed to examine the IPDC file repair mechanism. More specifically, it is used to examine resulting financial ptp and ptm repair costs in different simulation scenarios. The research shown focuses on the broadcast transmission of time-uncritical binary data objects, such as applications, images, ring tones, songs, or other data using an existing IPDC/DVB-H infrastructure. These data objects need to be delivered lossless, therefore the transmission relies on the IPDC/DVB-H file repair mechanism. For the examination of different aspects of this file repair mechanism, a simulation framework has been developed. The framework is based on the open source simulation tool OMNeT++ (Varga, 2009) and implements current error models for the wireless transmission channel as well as additional forward error correction measures (MPE-FEC, see section 2.2). It supports the simulation of both ptp and ptm file repair sessions, which are basically depicted in section 3.1. The calculations of expected and actual financial file repair costs are based on the formulas specified in (DVB Project, 2009b) and described in section 3.2.
The most important research questions of the study concerning the transmission of a single file to a varying number of receivers were:

- What are the financial file repair costs of both ptp and ptm repair sessions?
- What are the effects of different MPE-FEC frame sizes on the repair costs?
- What are the influences of different encoding symbol sizes on the repair costs?

In the context of this study, the costs for the first rounds of file repair sessions are compared. For ptp repair sessions, one round should be sufficient because each receiver gets its individual repair data from the repair server via an individual bidirectional connection. For ptm sessions, further rounds could be necessary until all receivers have received complete and error-free data.

#### 4.1 Simulation topology

Figure 9 shows the general topology used for conducting the simulations. The component *Sender* represents the IPDC/DVB-H sender, which broadcasts binary data objects to the receivers. The broadcast transmission is represented by the component *PacketBroadcast*. This component simply replicates a packet sent by the sender for each receiver. The component *Receiver* incorporates the error model for the transmission channel and the optional MPE FEC error correction (see section 2.2). In this example, two receivers send file repair requests to the component *FileRepairServer* which receives file repair requests from the receivers and conducts cost calculations (see section 3.2).

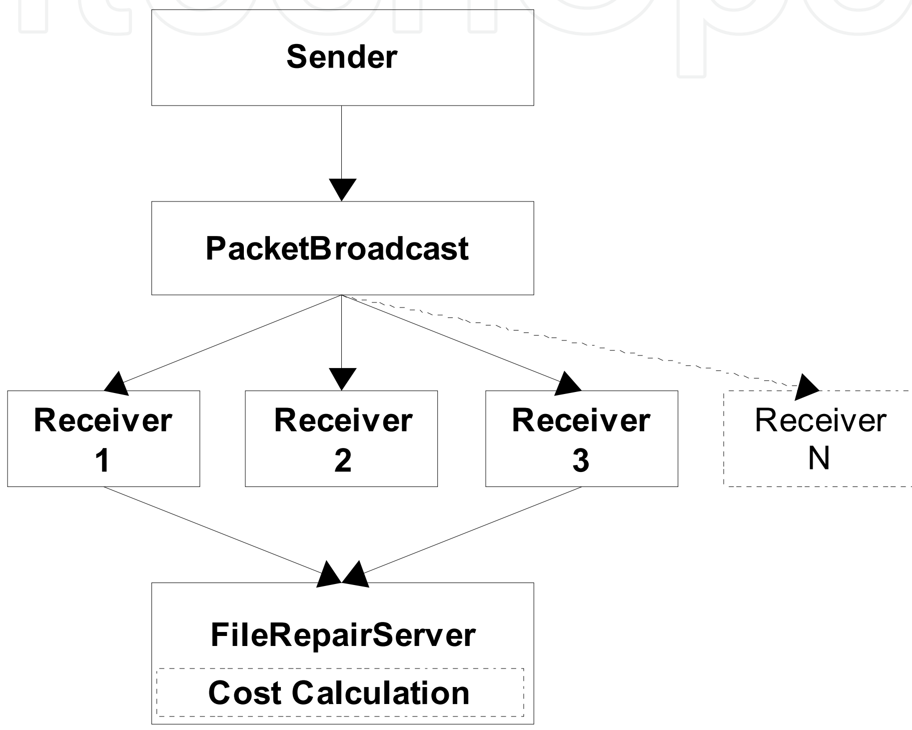


Fig. 9. Simulation topology.

The following parameters can be set for the component *Sender*: size of the data object to be transmitted (file size), size of an encoding symbol (each encoding symbol is the payload of a FLUTE packet), number of encoding symbols per source block, sum of additional protocol overheads (FLUTE/ALC, UDP, IP), and MPEG-2 TS data rate.
The component *Receiver* allows the configuration of the following parameters: file size, encoding symbol length, number of encoding symbols per source block, number of rows of the MPE-FEC frame (optional), DVB-T transmission mode (2K, 4K or 8K), minimal distance from sender in km, offset time and random time period for sending file repair requests after the transmission is finished.
Figure 10 shows the most important parts of the component *Receiver* in more detail. Each encoding symbol is transported within a FLUTE packet, which itself is mapped to TS packets of the used MPEG-2 TS. The error model described below is applied to the received stream of TS packets. Depending on the states of the error model, this results in no or several erroneous TS packets. If MPE-FEC is used, some or all of these erroneous TS packets can be recovered. Unrecoverable encoding symbols are listed in the table of erroneous symbols and can be requested at the file repair server after the transmission of the file is finished.

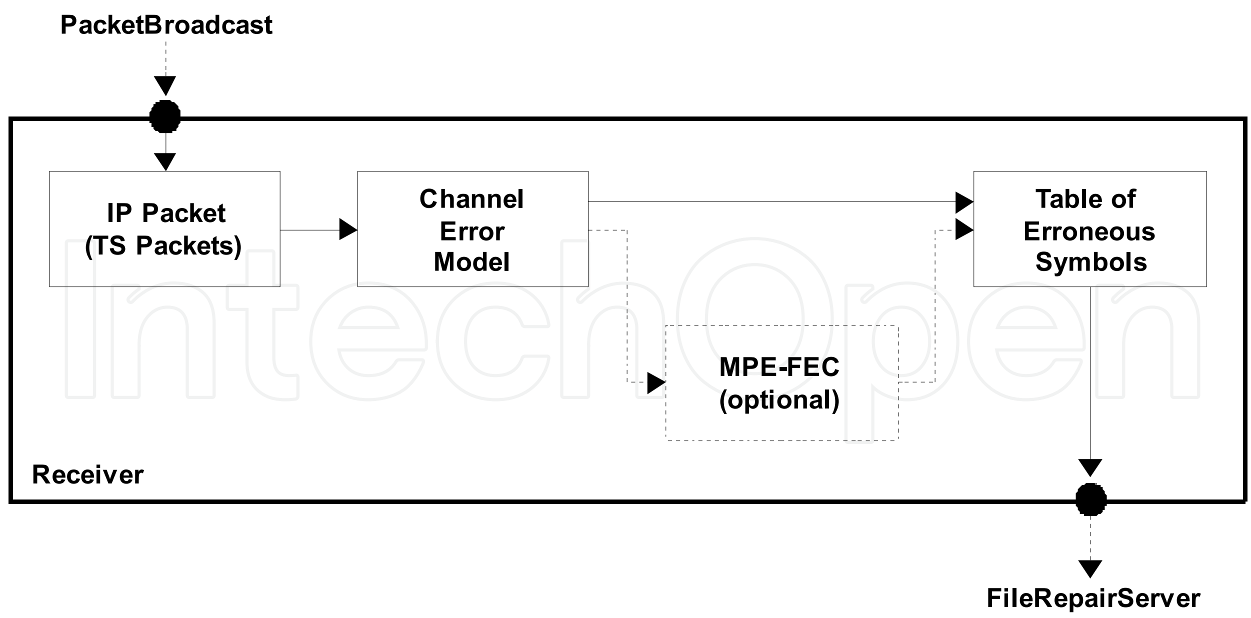


Fig. 10. Details of the component Receiver.

The following parameters can be set for the component *FileRepairServer*: number of receivers, cost for the transmission of a single byte via the ptp network, cost for the transmission of a single byte via the ptm network, offset time and maximum back-off time for receiving file repair requests after the transmission is finished, fraction of the maximum back-off time for the calculation of estimated repair costs (α), file size, average symbol size, average size of a file repair request, size of a ptm repair session announcement, estimated success rate for a receiver using a ptm repair session, and fraction of receivers without a ptp connection.

Error Model of the Transmission Channel

To simulate erroneous data segments, an error model had to be implemented into the transmission system of the simulation framework. The error model used is based on the so-called four-state run length model described in (Poikonen & Paavola, 2006) and (Poikonen & Paavola, 2005). This model operates on the resulting MPEG-2 transport stream of the DVB-T data transmission (see section 2.2) and produces streams of erroneous TS packets by using the four states *Good (short)*, *Bad (short)*, *Good (long)* and *Bad (long)*. If the model is in the states *Bad (short)* or *Bad (long)*, erroneous TS packets are generated, and if the model operates in the other two states, correct TS packets are produced.
According to the state diagram of this model (Poikonen & Paavola, 2006), the probabilities for remaining in a state denoted as *long* are very high. Therefore, whenever the error model switches over to one of these states, it will remain there for a rather long period of time compared to the states denoted as *short*, leading to long sequences of erroneous or error-free TS packets. With these settings, the model has shown to produce a good approximation to error streams measured using the COST 207 Six-tap Typical Urban (TU6) multi-path channel model (COST, 1989). See (Poikonen & Paavola, 2006) for a comparison.

Modified ptm Repair Cost Formula

For the simulations done within this study, a modified formula (3) for the calculation of the ptm repair costs (see section 3.2) was used. This formula focuses on the characteristic that only distinctive erroneous symbols have to be retransmitted in a ptm repair session instead of the whole file as specified in the original formula for ptm sessions in (DVB Project, 2009b). Therefore, the parameter $n_{dsym}$ denotes the number of distinctive requested symbols. For the calculation of the actual financial ptm repair costs, the estimated value for the number of repair requests ($N_{req}$) is replaced by the actual value denoted by $n_{req}$.

$$C_{ptm(expected)} = c_m \cdot s_{an} + c_u \cdot N_{req} \cdot s_{req} + c_m \cdot n_{dsym} \cdot s_{sym} \quad (3)$$

Simulation Parameters

For all simulations done within this study, the size of the transmitted object (file size) was 4 MB. This is for example the typical size of an MPEG-1 audio layer 3 (MP3) encoded sound file. MPE-FEC either was disabled or enabled, using 256, 512 or 1024 rows for the corresponding MPE-FEC frames. With these settings, it was possible to compare the effectiveness of different MPE-FEC settings with regard to the resulting number of repair requests and therefore with regard to the resulting transmission overheads and repair costs. The size of an encoding symbol either was 100 bytes, 500 bytes or 1400 bytes. This allowed for the comparison of the effects of very small, medium-sized, and large FLUTE packets on the effective repair costs. The cost for the transmission of a single byte via the ptm network was based on the pricing published by an Austrian DVB-H provider which bills EUR 39700 excluding 20% value added tax (VAT) per 100 kbps stream per year[3] for nationwide coverage. This is equivalent to EUR $1.225 \cdot 10^{-7}$ per byte. The cost for the transmission of a single byte via the ptp network was based on the pricing published by an Austrian mobile network operator that bills EUR 10 including 20% VAT per 1 GB per month[4] for nationwide coverage. This equates to EUR $1 \cdot 10^{-8}$ per byte. After one-third of the time window for repair requests, the calculation of the projected repair costs was done by the file repair server. Other parameters, e.g. concerning values for the DVB transmission mode and TS data rate were set to typical, technical parameters of current DVB-H trial services (DVB Project, 2009a) or according to examples in (DVB Project, 2009b) and (DVB Project, 2009c).

### 4.2 Simulation results

Figure 11 shows the financial repair costs for a transmitted file of size 4 MB without MPE-FEC for up to 1000 receivers. Whereas the costs for ptp sessions rise almost linearly with the number of receivers, the costs for ptm sessions quickly converge to a maximum. This maximum represents the correction of the whole file. These different behaviors are due to the fact that in a ptp repair session each requested symbol has to be transmitted to the requester individually, whereas in a ptm session only distinctive requested symbols are repeated, independent of the number of different requests for one and the same symbol.

Figure 12 shows the file repair efficiencies of the ptp and ptm repair sessions for up to 5000 receivers. The file repair efficiency is defined in (DVB Project, 2009b) as the number of receivers with successful recovery divided by the cost of the transmission of repair data. For ptp sessions, the number of receivers with successful reception is given by the total number of receivers, because it is assumed that all receivers will be successful. For ptm sessions, it is

[3] http://www.ors.at/bekanntmachungen/301.pdf (18.06.2009)
[4] http://www.a1.net/privat/breitband (18.06.2009)

assumed that there will be a fraction of the receivers that are still not able to recover the file after the first round of the ptm repair session. In the simulations done, it is assumed that 90 % of the receivers will be able to recover the file after the first round of the ptm session. Due to the fact that the ptm repair costs are independent of the number of receivers, ptm sessions result in higher efficiencies, especially when there are many receivers.

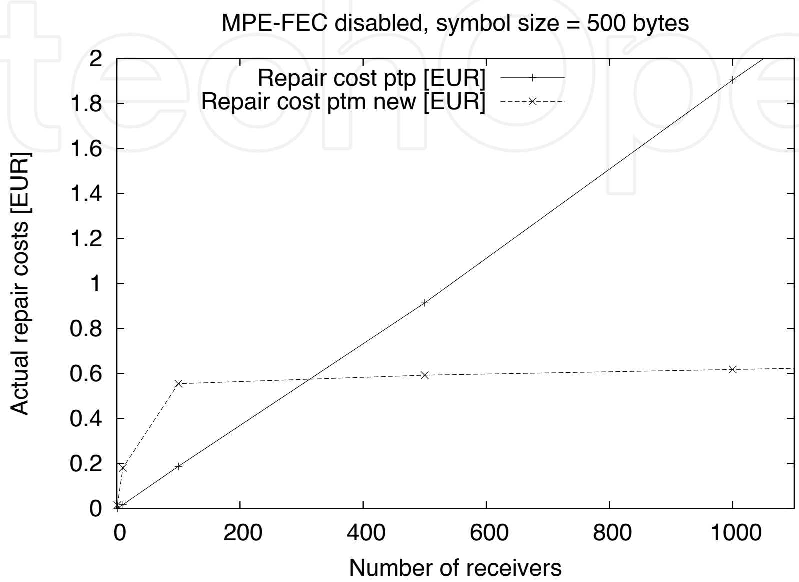


Fig. 11. File repair costs without MPE-FEC.

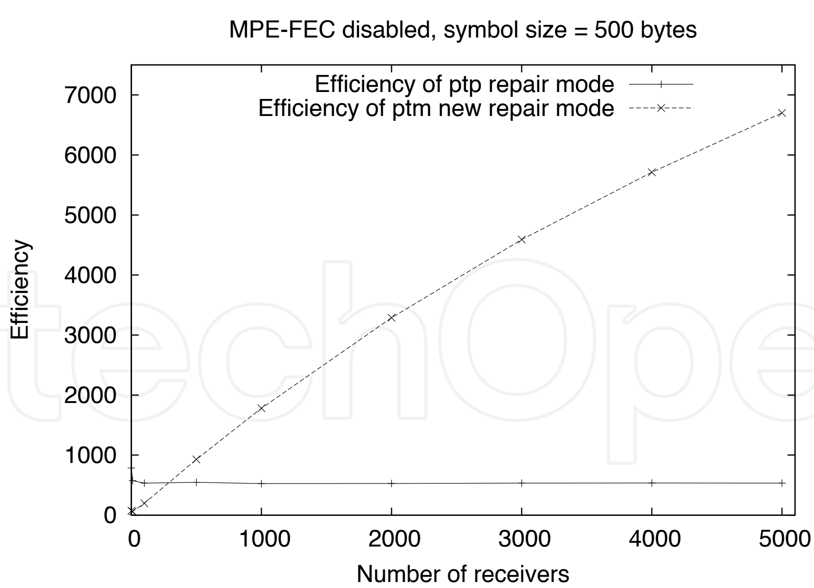


Fig. 12. Efficiencies of the different file repair methods.

Figure 13 compares the expected and actual file repair costs for ptp and ptm repair sessions without MPE-FEC. It can be seen that the expected costs are very close to the final costs, although the calculation of the expected costs was done at only one-third of the repair request window (α = 0.33).

The results of the simulations which explore the impact of MPE-FEC for additional forward error correction are shown in figures 14 and 15. Figure 14 compares the resulting amount of necessary repair data for ptp repair sessions depending on the used MPE-FEC frame size. As can be seen clearly, the bigger the MPE-FEC frame size, the lower the amount of erroneous data. This is due to the fact that the probability of being able to recover a single IP packet is higher when the MPE-FEC consists of more rows, because the shorter the frame the higher the probability that an IP packet spans several columns.

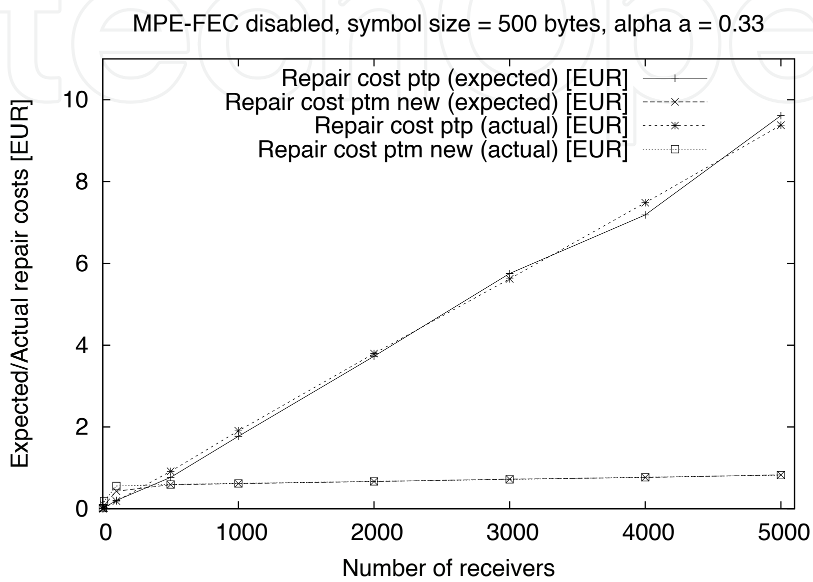


Fig. 13. Expected vs. actual file repair costs.

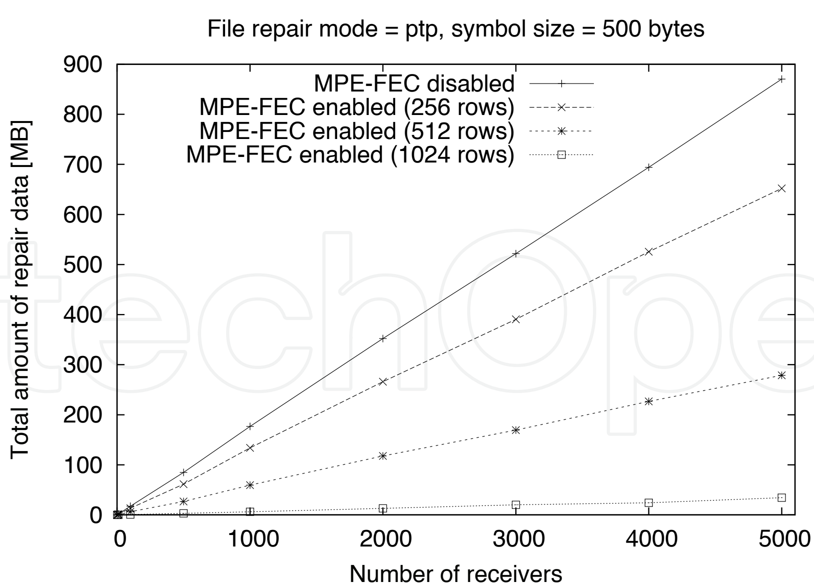


Fig. 14. Effects of MPE-FEC on ptp repair.

Concerning ptm sessions, the amount of repair data converges to the file size including protocol overheads. The bigger the used MPE-FEC frames, the more slowly this convergence happens (see figure 15).

Figure 16 compares the ptp and ptm repair costs for the two cases of disabled and enabled MPE-FEC. As can be seen, ptp can outperform ptm, when MPE-FEC is used with the maximum MPE-FEC frame size due to ptp's lower transmission cost per byte.
Figures 17 and 18 show the comparison of ptp and ptm repair costs using maximum MPE-FEC frame size and different symbol sizes. For ptp repairs, the usage of a symbol size of 500 bytes yields better results than using a bigger symbol size of 1400 bytes or a very small symbol size of only 100 bytes.

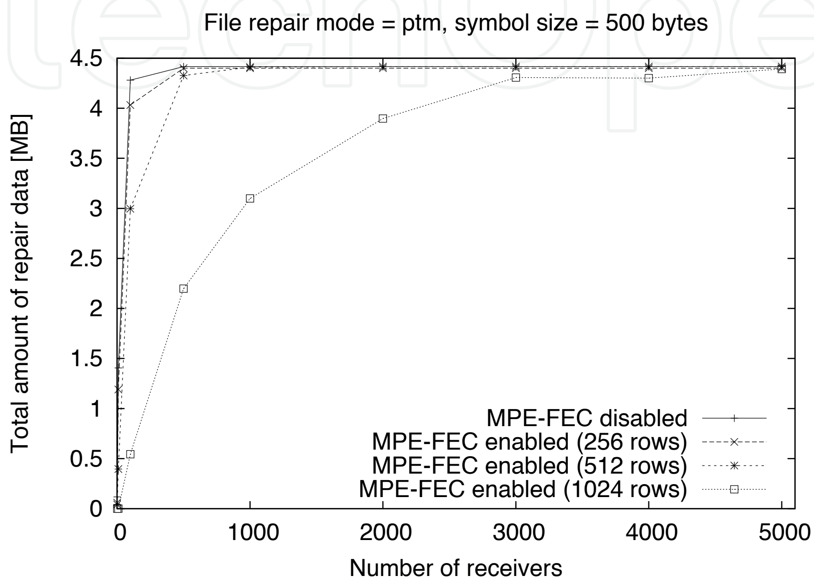


Fig. 15. Effects of MPE-FEC on ptm repair.

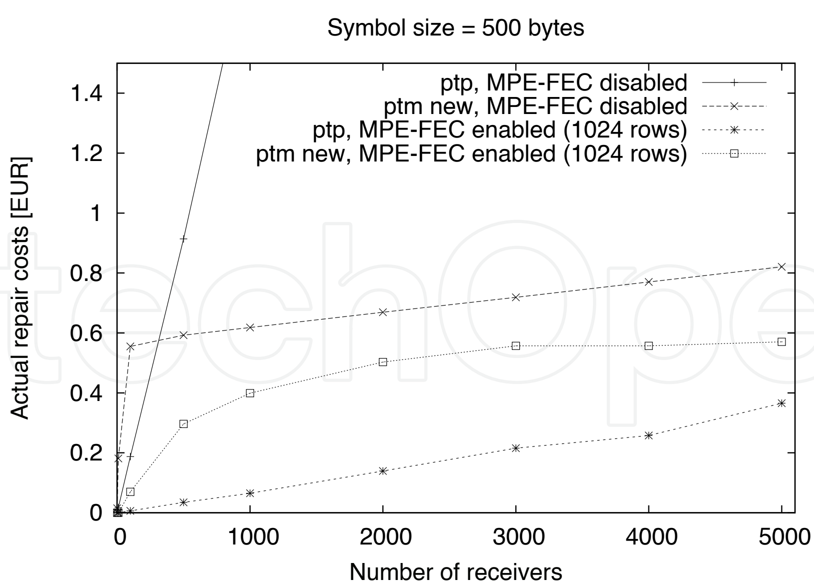


Fig. 16. File repair costs with/without MPE-FEC.

For large symbols, the probability of spanning several MPE-FEC frame columns is higher than for shorter symbols. As the number of bytes per row which can be corrected is limited by the used RS code, a symbol contained in only one column can more likely be corrected than a symbol distributed over several columns. Very small symbols have a misbalanced ratio between protocol headers and payload. Each symbol is prefixed with 52 bytes of FLUTE/UDP/IP encapsulation overheads. Therefore, very small symbol sizes intrinsically result in increased repair costs per user data.

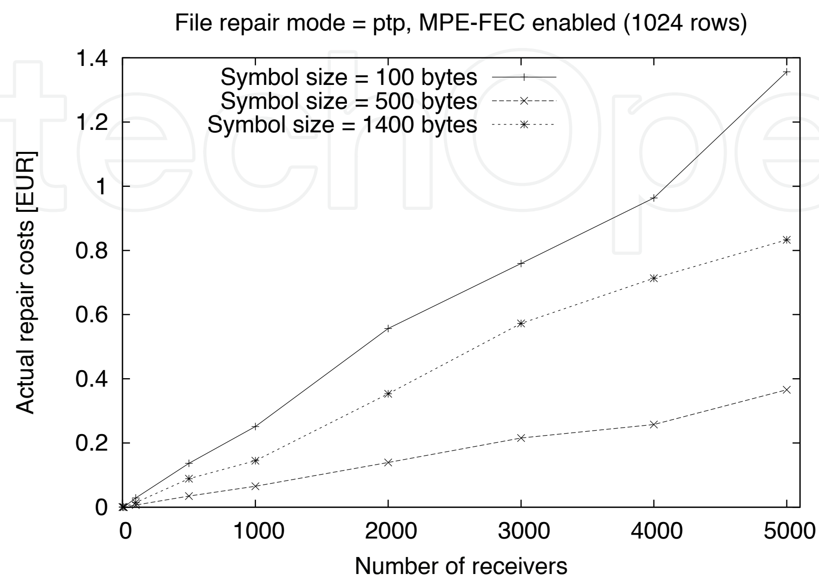


Fig. 17. Effects of encoding symbol size on ptp repair costs.

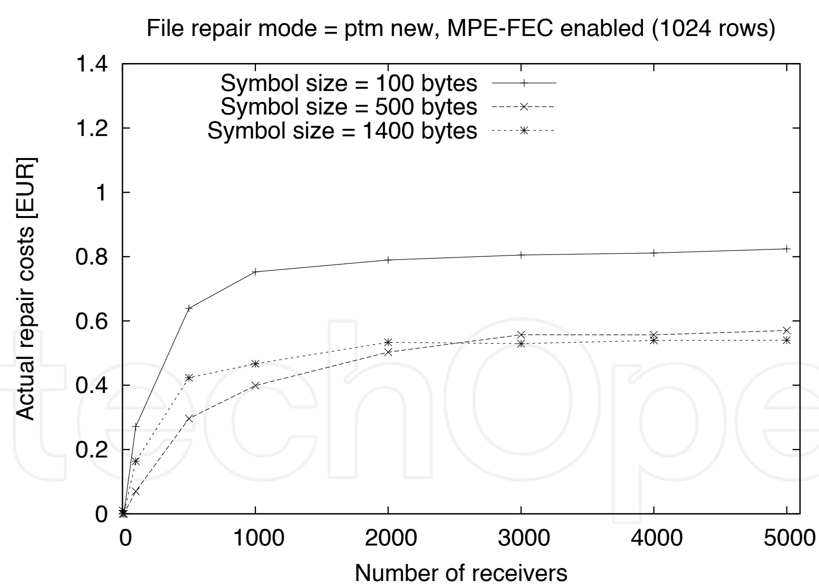


Fig. 18. Effects of encoding symbol size on ptm repair costs.

The results depicted in figure 18 dealing with ptm repairs show once again the negative effects of very small symbol sizes. As the amount of repair data for this repair mode converges to the file size, the symbol size with the most efficient payload/header ratio produces the lowest repair costs if a large number of receivers is considered. Summing up the results of both figures, the usage of medium-sized symbols is recommended.

## 5. Conclusions

IP datacast over DVB-H is one possible technical system to deliver mobile multimedia services, which are gaining more and more importance. This chapter gave an overview of the different digital video broadcasting transmission systems, including DVB-H and IP datacast. An IPDC/DVB-H infrastructure can provide different services, such as real-time streaming services for mobile TV or file delivery services for the distribution of arbitrary files to all receivers within the service area. Concerning the latter services, a file repair mechanism was specified for enabling the retransmission of data segments which were received erroneous at the receivers. In order to understand the technical details of the file repair mechanism and its technical context, the relevant building blocks and protocols were described in detail within the chapter.

A considerable part of the chapter deals with a simulation study to examine the financial costs of file repair sessions based on IPDC's file repair mechanism. This examination was done using a simulation framework, which incorporates the basic IPDC/DVB-H transmission and file repair procedures as well as a current error model concerning the DVB-H transmission channel. Simulations concerning the transmission of a file to a variable number of receivers with varying values for several critical parameters such as the use of MPE-FEC for error correction, the size of MPE-FEC frames, or the size of encoding symbols were executed. Three of the most important results of the simulations are as follows. First, the file repair costs of ptp repair sessions rise (almost) linearly with the number of receivers, whereas the file repair costs of ptm repair sessions rapidly converge to the costs of retransmitting the whole file. For a high number of receivers and without MPE-FEC for additional error correction, ptp repair costs are considerably higher than ptm repair costs. Second, MPE-FEC can drastically reduce the amount of repair data necessary for data recovery, especially concerning ptp repair sessions. The bigger the used MPE-FEC frame, the lower the rising of the file repair costs, especially concerning ptp repair sessions. The biggest MPE-FEC frame size (1024 rows) provides the best results. Depending on the number of receivers, the ptp repair mode can outperform the ptm repair mode, if MPE-FEC is used. Third, the size of the encoding symbols has a strong impact on the repair costs. Neither very big symbols nor very small symbols lead to optimal results. It is recommended to use medium-sized symbols of about 500 bytes.

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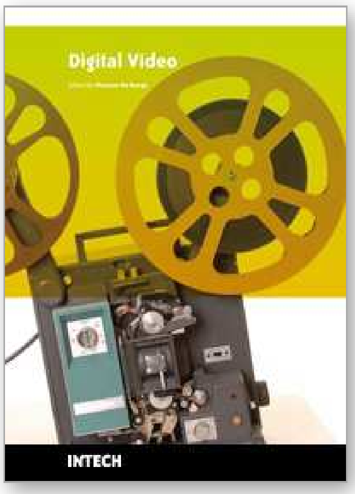


**Digital Video**

Edited by Floriano De Rango

ISBN 978-953-7619-70-1
Hard cover, 500 pages
**Publisher** InTech
**Published online** 01, February, 2010
**Published in print edition** February, 2010

This book tries to address different aspects and issues related to video and multimedia distribution over the heterogeneous environment considering broadband satellite networks and general wireless systems where wireless communications and conditions can pose serious problems to the efficient and reliable delivery of content. Specific chapters of the book relate to different research topics covering the architectural aspects of the most famous DVB standard (DVB-T, DVB-S/S2, DVB-H etc.), the protocol aspects and the transmission techniques making use of MIMO, hierarchical modulation and lossy compression. In addition, research issues related to the application layer and to the content semantic, organization and research on the web have also been addressed in order to give a complete view of the problems. The network technologies used in the book are mainly broadband wireless and satellite networks. The book can be read by intermediate students, researchers, engineers or people with some knowledge or specialization in network topics.



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