A Novel Algorithm for Decapsulation and Decoding of DVB-H Link Layer Forward Error Correction

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***Abstract*— DVB-H, which is an amendment of DVB-T, offers reliable high data rate reception for mobile handheld and battery-powered devices. A link layer with error correction is defined to work on top of the DVB-T physical layer. The DVB-H standard suggests to use Reed-Solomon coding combined with cyclic redundancy check error detection as the link layer forward error correction. Drawbacks of the decoding solution have been recognized in previous research. This paper presents a novel algorithm for decapsulation and decoding at DVB-H link layer. The algorithm is based on information provided in the transport stream packet headers and requires no changes to the DVB-H standard.**

Keywords - DVB-H, Reed-Solomon, error decoding, erasure decoding, simulation

I. INTRODUCTION

In November 2004 the European Telecommunications Standards Institute (ETSI) ratified the standard for digital video broadcasting for handheld reception (DVB-H) [1], which is an amendment of the standard for terrestrial digital video broadcasting (DVB-T) [2] for handheld terminals. Changes were needed to enable low power consumption, more flexibility in network planning, better mobile performance and compatibility with IP (Internet protocol) networks. These were achieved by adding a time-slicing operation for power saving, error correction to combat effects of receiver mobility and a new 4K OFDM (Orthogonal Frequency Division Multiplexing) mode in addition to the 2K and 8K modes in DVB-T to facilitate network planning. The time-slicing operation means that transmission occurs in bursts. The power-saving feature is due to the fact that the receiver can switch off radio components between bursts. The new OFDM mode offers a compromise between the good Doppler performance of the 2K mode and the good suitability for large SFNs (Single Frequency Network) of the 8K mode. OFDM mode refers to the size of the FFT (Fast Fourier Transform) component, which determines the number of carriers in the system.

The approach to combat the effects of receiver mobility is link layer forward error correction (FEC) code denoted with RS(255,191), which means that code is Reed-Solomon (RS) code having 191 input data bytes and outputting 255 encoded bytes, thus the number of redundancy bytes is 64. To facilitate error detection at the receiver, cyclic redundancy check (CRC) is also performed for encoded RS data.

The DVB-H standard does not define the decoding method for link layer. The system designer may utilize error detection information, such as CRC data, and perform erasure decoding, or alternatively, ignore the received error detection data and use the conventional Reed-Solomon decoding algorithm. An erasure occurs when the location of the erroneous byte is known but not the correct value. For errors, neither location nor value is known.

Previous research has shown that the decoding scheme utilizing CRC information in decoding as suggested in the DVB-H standard is inefficient, since a great amount of correctly received bytes are lost. In [3] it is concluded that more efficient methods to utilize signaling overhead caused by CRC or more powerful decoding methods should be sought. One possibility to improve system performance is to use MPEG-2 transport stream (TS) packet header data as erasure information as presented in section II.

This paper presents a novel method for IP data decapsulation and decoding at DVB-H link layer called *hierarchical decapsulation and decoding*. The algorithm makes use of all received data to enable more powerful decoding. Instead of just reliable and unreliable information for data, we get three levels of reliability: correct data, low priority data, which might be correct but there exists amount of uncertainty, and lost data. The algorithm is presented together with simulation results showing the gain of the new decoding scheme. The proposed algorithm is also compared to other possible decoding methods.

The paper is organized as follows: DVB-H link layer as defined in [1] is presented in section II. In section III, the proposed algorithm for decapsulation and decoding at the link layer is presented. Different decoding approaches are compared in section IV with computer simulations. Finally, concluding remarks are given in section V.

II. DVB-H LINK LAYER

A conceptual diagram of the DVB-H system is illustrated in Fig. 1. The physical layer consists of the DVB-T

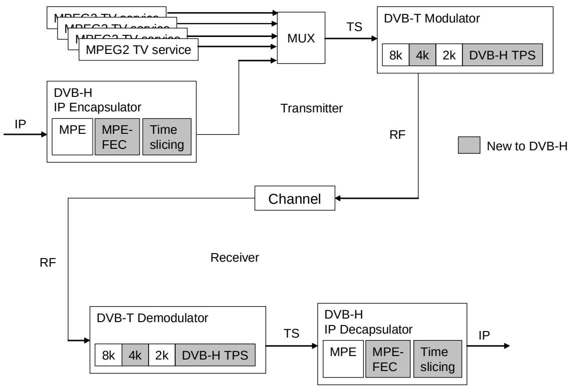

Figure 1. A conceptual description of the DVB-H system [1].

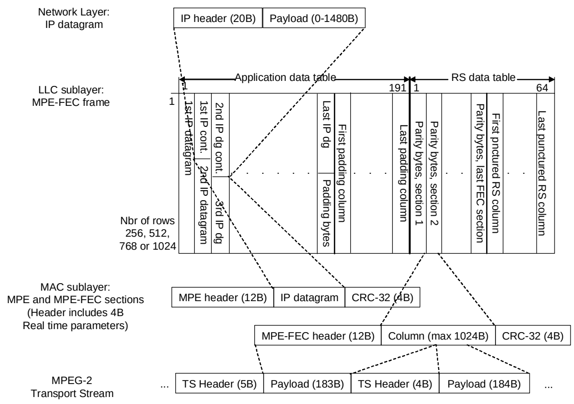

Figure 2. The link layer packets of DVB-H

modulator and demodulator and the link layer consists of the IP encapsulator and decapsulator. DVB-H services can optionally share mux with DVB-T services as presented in Fig. 1. Operations performed by DVB-H link layer are illustrated in Fig. 2.

The size of the MPE-FEC (Multi-Protocol Encapsulation – Forward Error Correction) frame is service independent. The number of rows can be 256, 512, 768 or 1024, depending on the wanted burst size. The number of data columns is 1-191 and the number of redundancy columns is 0-64. The IP datagrams are encapsulated column-wise into the MPE-FEC frame and the data are encoded row-wise using RS(255,191) code.

Different MPE-FEC code rates are achieved with code shortening and puncturing. The code rate is 3/4 if all 191 data columns and 64 redundancy columns are used. Other conceivable code rates are 1/2, 2/3, 5/6 and 7/8.

The frame is divided into sections so that an IP datagram forms the payload of an MPE-section and a redundancy column form the payload of a FEC-section. When the section header is attached, the CRC-32 redundancy bytes are calculated for the section. The MPE-sections are transmitted first and then the FEC-sections. The sections are transmitted in a MPEG-2 transport stream (TS) format [4], where a TS packet consists of a 4-5 byte TS header and 183-184 bytes of payload. This procedure is illustrated in Fig. 2. The TS packet header information is presented in detail in section II-A due to its importance for the proposed decoding algorithm. The MPEG-2 format for transport packets is inherited from DVB-T standard to ensure the compatibility of DVB-H with the existing DVB-T networks.

The receiver performs decapsulation of the received transport stream. The sections are decapsulated into the MPE-FEC frame and the bytes of a section are marked as "reliable" or "unreliable" depending on the CRC-32 decoding. The decoder can correct as many erasures, i.e. unreliable bytes, on each row of the MPE-FEC frame as the number of transmitted redundancy columns. Thus, using code rate 3/4, decoding is successful if a row of the MPE-FEC frame contains no more than 64 erasures.

In the DVB-H standard a Reed-Solomon decoding scheme with erasure information based on CRC-32 is suggested. The CRC-32 code is used for section error detection. When the IP datagrams can be up to 1500 bytes, a lot of correctly received data are marked as unreliable, when the CRC-32 check fails.

A more efficient way of erasure decoding would be to use the TS packet header for erasure information. The sections are transmitted in TS packets, whose headers include a *transport_error_indicator* (TEI) bit, which can be used for error detection. The TEI indicates whether the physical layer decoder was able to correct errors caused by the noisy fading channel. The physical layer RS(204,188) decoder sets the *transport_error_indicator* to '1' if it is unable to decode the 188-byte TS packet, i.e. it contains more than 8 byte errors.

When studying *section erasure* (SE) decoding, a complete section is marked as unreliable, if it contains an error. In *TS erasure* (TSE) decoding one TS packet is marked as unreliable, if it contains an error. For erasure decoding with code rates 1/2 and 3/4, a maximum of 64 erasure bytes are allowed on one row in the MPE-FEC frame. For non-erasure (NE) decoding the allowed amount of byte errors is 32 per row for code rates 1/2 and 3/4. Frames consisting of at least one row that cannot be decoded are considered erroneous.

A. The TS packet header

The TS packet header presented in table 1 consists of four or five bytes. The fifth byte is in use if the TS packet contains the first byte of a section.

The *transport_error_indicator* is set to '0' if the physical layer decoder is able to decode the packet. Otherwise it is set to '1'. Other important TS header components are the *packet _identifier* (PID) and the *continuity_counter*. If the PID is incorrect, the TS packet will be lost, since it cannot be recognized as part of the stream. The *continuity_counter* is an incrementing 4-bit number that helps discovering if a TS packet has been lost.

TABLE I. THE TRANSPORT STREAM PACKET HEADER [4]

Syntax	No. of bits	Description
sync_byte	8	Fixed value
transport_error_ indicator	1	Set to '1' by lower layer if erroneous packet. (Abbr.: TEI)
payload_unit_ start_indicator	1	Set to '1' if section starts in this packet. (Abbr.: PUSI)
transport_priority	1	Set to '1' if high priority
packet_identifier	13	Identifies one elementary stream. (Abbr.: PID)
transport_ scrambling_ control	2	Scrambled / User-defined
adaption_field_ control	2	Indicates if adaption_field is used
continuity_ counter	4	Incrementing with each packet with same PID
pointer_field	8	Used if PUSI='1'. Points at first element of a section.

III. THE ALGORITHM FOR HIERARCHICAL DECAPSULATION AND DECODING

In the following, a novel algorithm for the decapsulation of TS packets into MPE-FEC frame and FEC decoding called hierarchical decapsulation and decoding is presented. Hierarchical erasure information can be obtained for sections or TS packets as in basic erasure decoding described above. The decoding methods are *hierarchical section* (HS) decoding and *hierarchical transport stream* (HTS) decoding.

A. Hierarchical decapsulation

Hierarchical decapsulation aims to lose as small amount of data as possible. Like erasure decoding it is based on an Erasure Info Table (EIT), a matrix of the same size as the MPE-FEC frame, used for keeping track of the reliability of each byte of the frame. In hierarchical decapsulation the reliability of a byte in EIT can have three different values. In HTS decapsulation bytes carried in reliable TS packets, with TEI='0', are marked with zeros in the EIT. Lost TS packets are packets, whose PID has been corrupted. The location of a lost packet can be found using the *continuity_counter*. If the counter indicates that a packet is lost, the byte positions of that packet in MPE-FEC frame are filled with zero padding and marked with ones in the EIT. In fact, the padding could be any random data, since it is required only for assignment of packets into the received MPE-FEC frame.

The remaining packets are unreliable packets due to value of TEI='1', but their PID is received correctly. Although the TEI value indicates that these packets contain errors, they are not dropped, which would be the standard solution, but they are decapsulated into the MPE-FEC frame with low priority, and marked with 'X' in the EIT. In this context, the low priority means that the decapsulated data cannot overwrite correct data but a later decapsulated correct packet can overwrite a low priority packet.

The HS decapsulation scheme utilizes the transmitted CRC erasure information. A section, whose CRC-32 check fails but that can be decapsulated into the MPE-FEC frame is marked with low priority. This will be the case, when errors occur in the payload but not in the section header. Still, if wishing to decapsulate as much data as possible, it is essential to fill lost TS packets with padding.

B. Hierarchical decoding

Hierarchical decoding is based on error or erasure decoding or both depending on which is most efficient for the error pattern. It is well known [5, 6] that any code of distance d corrects for sure t_e erasures and t_u errors whenever

$$t_e + 2t_u < d\ . \qquad (1)$$

For RS code the d equals to the number of redundancy bytes plus one. If pure erasure decoding is used, the amount of corrected erasures equals the amount of redundancy bytes available, which is for example 64 for MPE-FEC code rates 1/2 and 3/4. If the code is punctured to obtain other code rates, the number of available redundancy bytes is smaller.

Decoding is performed row-wise to the received MPE-FEC frame, so that each row is treated as its own code word. Decoding is carried out based on the EIT information from the hierarchical decapsulation as follows:

1. All bytes marked with '1' or 'X' in the EIT are treated as erasures, t_e. Pure erasure decoding is performed if (1) is valid on this row of the MPE-FEC frame (t_u is set to zero). If (1) indicates that pure erasure decoding is impossible due to too many erasures, proceed to the second stage.
2. All bytes marked with '1' on this row of the EIT are treated as erasures (t_e). Bytes marked with 'X' in the EIT are treated as possible errors. Use what is left of the code distance d for error decoding. If the amount of errors t_u of the bytes marked with 'X' fulfills the inequality $2t_u < d - t_e$, the row can be decoded. Otherwise decoding fails and a frame error occurs.

Example:

The minimum distance of the RS(255,191) code with code rate 3/4 is d = 65. Consider the case that a row of the EIT contains 32 bytes marked with '1', 33 bytes marked with 'X' and 190 bytes marked with '0'.

Let us first try decoding according to step 1 of hierarchical decoding. Since there are 65 bytes marked with '1' or 'X', pure erasure decoding is not possible. Inequality (1) will not be fulfilled when t_e = 65 and t_u = 0. It is necessary to proceed to step 2 of hierarchical decoding.

When considering only bytes marked with '1' in EIT as erasures, t_e = 32. The inequality (1) will be fulfilled if $t_u \leq 16$. By using conventional Reed-Solomon decoding algorithms for erasures and errors, the locations of the errors will be found and the code word can be decoded. If there are more than 16 errors in the low-priority bytes marked with 'X', decoding will fail. If there is at least one row of the

MPE-FEC frame that cannot be decoded, a whole frame will be lost.

IV. PERFORMANCE EVALUATION

Simulations were carried out to compare link layer MPE-FEC frame error ratio (MFER) for decoding methods discussed in this paper as a function of the signal-to-noise ratio (SNR). Five different decoding methods discussed earlier are considered: section erasure (SE) decoding, hierarchical section (HS) decoding, TS erasure (TSE) decoding, hierarchical TS (HTS) decoding and conventional non-erasure (NE) decoding.

Criteria in the selection of simulation parameters were to choose parameters, which are likely to be adopted in commercial systems. The following link layer parameters were chosen for the simulations: the MPE-FEC frame has 512 rows, the code rate is chosen to be 1/2 and 3/4, i.e. 64 or 191 data columns and 64 RS columns are used. The input data to the link layer in the transmitter is IP datagram. For these simulations a constant length of 512 bytes for IP datagrams were chosen for simplicity, i.e. one IP datagram is transmitted in one section corresponding to one column of the MPE-FEC frame. One section erasure leads to one column erasure in the MPE-FEC frame, when IP datagram length equals number of rows in the MPE-FEC frame.

Physical layer (PHY) is the DVB-T physical layer defined in [2] with the following parameters: modulation 16QAM, convolutional code rate 1/2, OFDM FFT size 8K and guard interval 1/4. Physical channel model is the COST207 TU6 [7] six-tap multipath channel corresponding to typical urban propagation conditions. Mobility of the receiver is inspected with Doppler frequencies 2 Hz, 10 Hz, 30 Hz and 80 Hz.

A. *Physical layer simulator*

The physical layer performance in multipath case was measured from real DVB-T equipment when a hardware channel simulator was used due to excessive duration of bit-true computer simulations. The measurement setup is illustrated in Fig. 3.

In measurements MPEG-2 source data was transmitted using DVB-T modulator. Modulated signals were passed through the hardware channel simulator using six-tap multipath profile from [7]. Doppler shift caused by mobility of the receiver and signal-to-noise ratio were adjustable parameters in the simulator. The noisy signal was input to DVB-T/H receiver followed by logic analyzer to produce a TS error trace. Measurement device allowed recording of *transport_error_indicator* bit from each TS packet. Thus, for link layer simulations only the information about the correctness of the TS packet was available.

B. *Link layer simulations*

As only the exact TS Packet Error Rate (PER) is known at the link layer input, an approximation about the amount of erroneous bytes in each erroneous TS packet is made. The amount of byte errors is 20-45 per erroneous TS packet for TS PER up to 20%. Higher PER values are not considered, since they cause unacceptably high frame error ratios. The approximation applies well for all the parameters considered in the simulations. The byte errors are assumed to occur in a burst in the erroneous TS packets

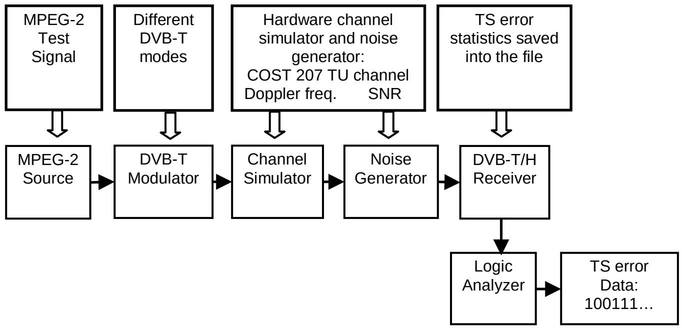

Figure 3. Measurement setup for obtaining TS packet error traces

The results of the simulations are presented in figures 4-7 and tables II-III. In the figures, the results of the simulations are presented as MPE-FEC Frame Error Rate (MFER) after decoding as a function of the signal-to-noise ratio. MFER is the ratio of uncorrected MPE-FEC frames during the observation period, and it is an established quality criterion in DVB-H [8]. The MFER range chosen for inspection is from 1% to 5%. It is expected that sufficient quality of service for streaming video applications is achieved with MFER smaller than 5%.

1) *MPE-FEC FER as a function of SNR*

The MFER for different decoding methods is compared as a function of SNR with the MPE-FEC code rates 3/4 and 1/2 in Fig. 4 and Fig. 5, respectively. The Doppler frequency is 10 Hz. Hierarchical decoding (solid lines) is obviously stronger than erasure decoding (dashed lines). Also, it is clear that decoding based on the transport error indicator (circles) is stronger than decoding based on CRC-32 erasure information (triangles). The curve of non-erasure decoding (squares) is also better than the curves of both erasure decoding methods, but coincides with the curve for hierarchical section decoding.

Signal-to-noise ratio values to achieve MFER of 1% and 5% are illustrated in table II. The gain of using hierarchical TS decoding instead of section erasure decoding is 1.3 dB when MFER is 1%. Using hierarchical section decoding instead of section erasure decoding gives a gain of 0.6 dB when MFER is 1%.

In [3] SE decoding was compared to NE decoding, and non-erasure approach was found to outperform section erasure. However, in [3] no TS packet losses were considered. NE decoding performance, when lost TS packets are not considered, is about the same as HTS in Fig. 5. As is shown, the performance of NE decoding will be worse, when the lost data is considered. Then NE decoding will have the same performance as HS decoding, which is outperformed by HTS decoding by 0.7 dB at MFER of 1%.

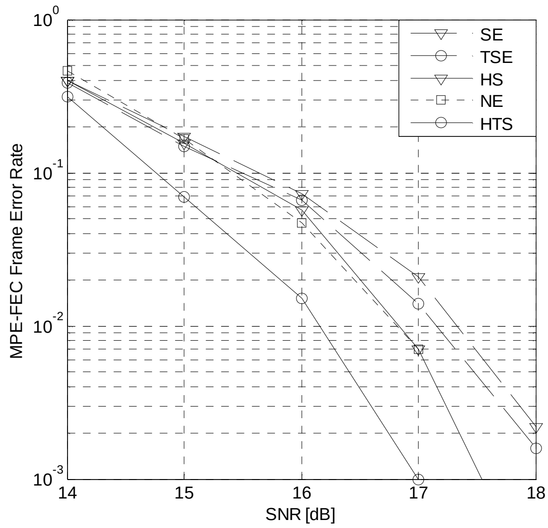

Figure 4. The performances of SE, HSE, TSE, HTS and NE decoding, when MPE-FEC code rate 3/4 and Doppler frequency 10 Hz.

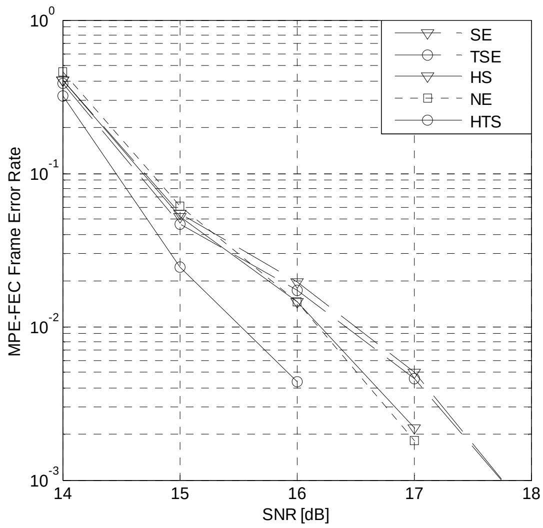

Figure 5. The performances of SE, HSE, TSE, HTS and NE decoding, when MPE-FEC code rate 1/2 and Doppler frequency 10 Hz.

TABLE II. SIGNAL-TO-NOISE RATIO TO ACHIEVE CERTAIN MFER FOR DIFFERENT DECODING RATES AND METHODS. 16QAM, DOPPLER FREQ. 10 Hz

FEC code rate	Decoding method	SNR[dB] @ 5% MFER	SNR [dB] @ 1% MFER
3/4	SE	16.3	17.3
3/4	TSE	16.2	17.1
3/4	HS	16.1	16.8
3/4	NE	16.0	16.8
3/4	HTS	15.2	16.1
1/2	SE	15.1	16.5
1/2	TSE	14.9	16.4
1/2	HS	15.0	16.2
1/2	NE	15.1	16.2
1/2	HTS	14.7	15.5

2) *Doppler performance*

To analyze the effect of receiver mobility the results of simulations with Doppler frequencies 10 Hz and 80 Hz are presented in Fig. 4 and Fig. 6, respectively. When the velocity of the receiver is increased, the number of errors increase but the error burst length of incorrect TS packets will be shorter, since the reception conditions are changing faster. Doppler frequency of 80 Hz corresponds to the receiver moving with a speed of about 160 km/h, when 10 Hz corresponds to about 20 km/h for carrier frequencies around 500 MHz. At high Doppler frequencies TSE decoding is stronger than HS decoding. The gain of using hierarchical TS decoding instead of section erasure decoding is the same as in the previous cases. However, hierarchical section decoding is quite weak. This is explained by the fact that the TS packet errors are more scattered in the MPE-FEC frame, making many sections unreliable. As in the previous cases, non-erasure decoding has the same performance as hierarchical section decoding.

Hierarchical TS decoding with code rate 3/4 will not be as strong as section erasure decoding with code rate 1/2, when the Doppler frequency is 80 Hz, though the gain compared to section erasure decoding with code rate 3/4 is the same as for lower Doppler frequencies. At high Doppler frequencies the gain of using a higher code rate is bigger.

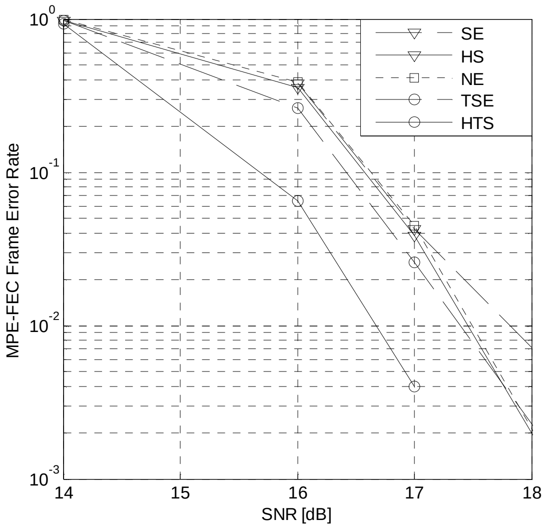

Figure 6. The performances of SE, HSE, TSE, HTS and NE decoding, when MPE-FEC code rate 3/4 and Doppler frequency 80 Hz.

In table III, the gain of using other decoding methods instead of section erasure decoding is presented for different Doppler frequencies. It is interesting to notice that the best reception is achieved at Doppler frequency 30 Hz, which corresponds to velocity of about 60 km/h. At this Doppler frequency the error pattern is the most favorable for the used interleaving and error correction schemes. At this velocity, also the gain of using better decoding methods is the smallest.

For Doppler frequencies 2 Hz, 10 Hz and 30 Hz HTS

TABLE III. DOPPLER PERFORMANCE GAIN OF USING DECODING METHOD DISCUSSED IN THIS PAPERCOMPARED TO SECTION ERASURE DECODING WHEN MFER = 1%

FEC code rate	Doppler freq.[Hz]	NE gain [dB]	TSE gain [dB]	HTS gain [dB]	HS gain [dB]
3/4	2	0.5	0.1	1.0	0.5
3/4	10	0.6	0.2	1.3	0.6
3/4	30	0.2	0.1	0.7	0.2
3/4	80	0.3	0.4	1.1	0.3

decoding with code rate 3/4 is stronger than SE decoding with code rate 1/2. In all other cases, except Doppler frequency 80 Hz, HS decoding is stronger than TS erasure decoding. HS decoding is notably stronger than section erasure decoding only for Doppler frequencies 2 Hz and 10 Hz.

V. CONCLUSIONS

A new method for decoding MPE-FEC at DVB-H link layer called *hierarchical decapsulation and decoding* was presented in this paper. The erasure information can be based on CRC-32 information (section erasure) or the *transport_error_indicator* in the TS packet header (TS erasure). Hierarchical decapsulation uses three levels of reliability for the decapsulated bytes: correct byte, low priority decapsulated byte or lost byte. Hierarchical decoding is based on erasure decoding or a combination of erasure and error decoding, depending on the reliability of the bytes in the code word.

In simulations the efficiency of hierarchical decoding at DVB-H link layer FEC was compared to erasure decoding based on CRC and TS packet header information, and conventional non-erasure decoding with different code rates. It is shown in this paper that arranging Reed-Solomon coding with cyclic redundancy check in the way it is suggested in the DVB-H standard [1] has inefficient decoding performance when compared to hierarchical decoding.

In the simulated cases hierarchical TS decoding demonstrated as good or better coding gain as section erasure decoding with lower a code rate. Choosing hierarchical TS decoding means that a higher code rate can be used, thus less redundancy is needed and more data can be transmitted. Alternatively the coding gain can be used by decreasing the output power in the transmitter.

Also, hierarchical section decoding has better performance than section erasure decoding. Still it seems unreasonable to use section based reliability information for sections that are longer than a TS packet, i.e. 184 bytes of payload, since erasure decoding based on TS packet header information performs better.

The hierarchical decoding algorithm will add some complexity to the decoder in comparison to section erasure decoding. The additional complexity is caused by the ability to perform hierarchical decapsulation and to perform erasure and error decoding if erasure decoding fails. The memory of the erasure info table also needs to be doubled for two-bit erasure information. Complexity analysis should be performed in future research.

Also, parsing of the sections was not considered in this paper. Parsing of the sections means finding the beginning and the end of each section from the received TS stream, by using information transmitted in the packet and section headers. TS erasure decoding seems to be more affected by ineffective parsing than section erasure decoding. Thus, the next step in development of DVB-H receivers is to find efficient parsing methods, in able to lose as few sections as possible. Hypothetically, if the four CRC-32 redundancy bytes are not used for section erasure information, the signaling overhead could be used for protection of the section headers to enable better parsing and decapsulation. This would, however, require changes to the standard.

An advantage of hierarchical TS decoding is that it does not require any changes to the existing DVB-H standard. Better decoding performance can be achieved by using all the information provided from lower layers and sublayers. The reliability information is provided by the RS(204,188) decoder at the physical layer and passed on the TS header. The *continuity_counter* in the TS header enables finding positions of lost TS packets, data that are lost. Most importantly, hierarchical decapsulation provides means to decapsulate all data that can be used for decoding of the MPE-FEC frame. It also provides means to choose the more efficient method of pure erasure decoding or erasure and error decoding for each row of the MPE-FEC frame. This way as little correct data as possible are considered unreliable.

It was concluded in [3] that more efficient methods to utilize signaling overhead caused by CRC or more powerful decoding methods should be sought. One solution for more efficient decoding was presented in this paper.

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