Improved Robustness for Channel Estimation without Pilots for DVB-T2

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Abstract—**As most state-of-the-art terrestrial transmissions standards, DVB-T2 uses orthogonal frequency division multiplexing (OFDM) as modulation scheme. For performing channel estimation and equalization normally so-called frequency domain pilots are employed. As pilots are known information to the receiver, they do not carry any information and are thus overhead. Therefore, DVB-T2 also allows for a mode with nearly no frequency domain pilots, whereby the channel estimation is based on the data itself. This paper shows the high performance and throughput benefits of this pilot-free transmission and blind channel estimation technique while proposing an optimized algorithm.**

Index Terms—**Mobile TV; DTV and broadband multimedia systems; Channel modeling and simulation; Channel coding, modulation, multiplexing**

I. Introduction

THE development of DVB's second generation terrestrial transmission standard DVB-T2 [1] has been finalized in May 2008. The first regular transmissions already started in the UK at the end of 2009 [2]. Compared to its predecessor DVB-T [3], DVB-T2 offers significantly increased performance in all types of channels. This is mainly caused by the new powerful forward error correction (FEC) codes and the increased flexibility of the OFDM parameters, which can adapt the guard interval length and the pilot density to specific requirements. DVB-T2 also offers the possibility to reduce the pilots for channel estimation, which offers a spectral efficiency gain of up to 8%. However, if this pilot pattern (PP) 8 is used, other means have to be employed to estimate the channel. One way is the so-called CD3 algorithm [4] that was originally proposed for DVB-T. Though, there is significant performance loss using the original algorithm that is mainly caused by the lower signal-to-noise ratios (SNR) DVB-T2 has to cope with compared to DVB-T, which is caused by the improved FEC performance. Hence, an optimised algorithm will be proposed within this document that achieves a performance close to the perfectly known channel case. Section II introduces the original CD3 channel estimation method, for which the pilot pattern PP8 has been designed. In section III an improved estimation algorithm is proposed, whose performance will be corroborated by the simulation results provided in section IV.

II. Channel Estimation For DVB-T2's No Pilot Mode

The effects of multipath propagation on OFDM (if the maximum excess delay is shorter than the Guard Interval length and the channel is slowly varying) can be modelled as the multiplication of the QAM symbol x in OFDM symbol l at subcarrier position k with the channel transfer function $H(l,k)$:

$$y(l,k) = x(l,k) \cdot H(l,k) + n(l,k) \quad (1),$$

where the additional noise term $n(l,k)$ is added for each OFDM subcarrier. The task of the channel estimator within the receiver is the estimation of the channel transfer function $\hat{H}(l,k)$, which is normally achieved by means of frequency domain pilots that are transmitted at specific OFDM subcarrier positions. The receiver then interpolates the channel transfer function, for which a large number of algorithms exists [6]. Hence, the receiver gets the equalized QAM symbols z:

$$z(l,k) = x(l,k) \cdot \frac{H(l,k)}{\hat{H}(l,k)} + \frac{n(l,k)}{\hat{H}(l,k)} \quad (2)$$

If the channel is estimated correctly, the receiver is able to correct the linear distortions completely, whereby the noise may be amplified, depending on the absolute value of $\hat{H}$.

However, it is also possible to estimate the channel if the transmitted data $x(l,k)$ is known to the receiver, which is the basis of the CD3 algorithm:

$$\hat{H}(l,k) = \frac{x(l,k) \cdot H(l,k)}{x(l,k)} + \frac{n(l,k)}{x(l,k)} \quad (3)$$

Naturally, this is normally not possible as the transmitted data is unknown to the receiver before the decoding process. However, it is known after the decoding process with a latency of one OFDM symbol, and can then be used for the estimation process. The block diagram of the CD3 algorithm using this principle is given in Figure 1. The receiver

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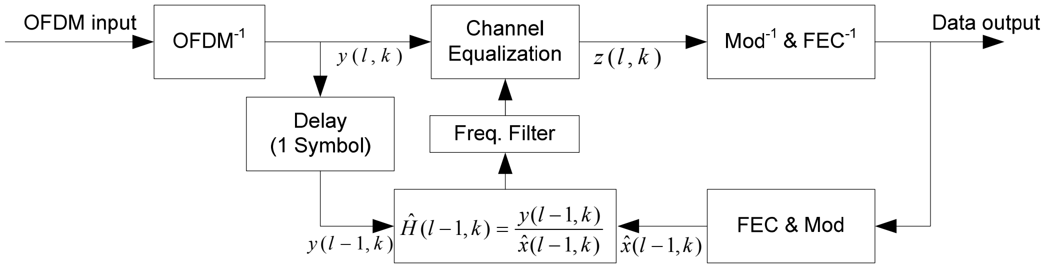

Figure 1: Principle of the CD3 equalization process

regenerates the complete data of each OFDM symbol after the decoding process, and hence, is able to use this algorithm for channel estimation. If the channel is assumed to be slowly changing, the equation

$$\hat{H}(l,k) \approx \hat{H}(l-1,k) \quad (4)$$

holds and one is able to estimate the channel using this algorithm.

In order to start this process, the receiver has to obtain the channel transfer function by other means, as this is not possible using this recursive algorithm itself. In case of DVB-T2, the P2 symbol within the preamble of each DVB-T2 frame can be used for this purpose. Afterwards, the recursive algorithm can be applied.

However, a problem of this algorithm is the presence of small absolute values of the inner QAM constellation points. Figure 2 depicts this problem for 16-QAM. If a mean power of 1 is assumed for the output signal, the absolute values of the inner constellations points are $|x_1|=0.31$, while the values for the outer constellation points are $|x_2|=1.34$, which correspond to a difference in amplitude of *12dB*.

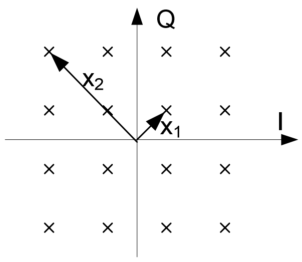

Figure 2: 16-QAM constellation diagram and absolute values for inner and outer constellation points

Hence, the inner constellation points lead to a noise amplification of *5dB* in equation (3) due to their small amplitude, while the noise term is reduced by *2.5dB* if the constellation points in the edges of the diagram are used. This estimation noise can be reduced by filtering the estimated signal, as depicted in Figure 1. However, only the filtering within one OFDM symbol is practically possible, because the future OFDM symbols are not available for filtering purposes, as this will additionally increase the latency of the algorithm.

III. Proposal For Improved Channel Estimation

As already mentioned, the amplification of the noise term on an individual OFDM subcarrier depends on the absolute value of *x*, i.e. the transmitted QAM constellation symbol. Hence, transmission systems as DVB-T or DVB-T2 use boosted pilots, which are transmitted at higher amplitude compared to the normal data. These pilots are in principle constellation points known to the receiver before the decoding process. Therefore, a promising approach is just the usage of the outer constellation points for channel estimation. This principle is depicted in Figure 3, while only the block calculating $\hat{H}(l-1,k)$ has to be modified in the block diagram of Figure 1. If the absolute value of the constellation point exceeds a threshold value, i.e. $|x| > x_{\min}$, this value is used for channel estimation. If not, it is linearly interpolated between two neighbouring positions that exceed this limit. As typically only a few OFDM subcarriers have to be interpolated, the loss in estimation accuracy is quite limited compared to the gain. After the interpolation process, the normal CD3 algorithm is applied. Additionally, it is also possible to filter the signal on the OFDM symbol to reduce the remaining estimation noise even further.

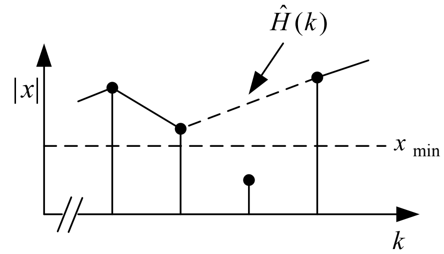

Figure 3: The channel is linearly interpolated over inner constellation points

Furthermore, the same principle can be applied if the LDPC decoder is not able to decode all subcarriers of an OFDM symbol. This effect occurs if an LDPC codeword is split over two OFDM symbols, which makes it practically impossible to correct the codeword before demodulating the following OFDM symbol.

IV. Simulation Results

This section presents the results obtained through simulations of the DVB-T2 system including the proposed algorithm for channel estimation. Different channel models have been evaluated, i.e. the AWGN (Additive White Gaussian Noise) channel, the DVB-T2 Rayleigh channel [5], and the time variant six-taps Typical Urban (TU-6) channel [7]. These channel models were chosen as they are commonly used for evaluating the performance of the digital video broadcasting standards. The DVB-T2 parameters employed for the simulations were mainly focused on stationary reception and high payload bitrates, as these are the intended modes for DVB-T2's PP8 scheme.

Furthermore, the results were obtained using the Matlab based DVB-T2 simulation chain of Mondragon University and the 'C' based simulator of TU Braunschweig. Realistic assumptions have been used for the different simulation blocks. For example the genie-aided demapper defined in the DVB-T2 Implementation Guidelines has not been used. Therefore, simulation results may also vary for the ideal channel estimation from the values given in the DVB-T2 Implementation Guidelines. Furthermore, the SNR values have not been corrected by the pilot boosting factors Δ_{BP} [5], as these were practically the same for all simulations (approx. 0.4dB). Additionally, only the non-rotated QAM constellations of DVB-T2 were used. However, the proposed algorithm is also applicable to rotated constellations.

The bandwidth of the frequency interpolation filter was matched to the different guard interval fractions in all cases, while linear interpolation was used in case of the pilot based channel estimation in the time direction. Furthermore, an ideal decoding of the feedback path for the CD3 and the proposed algorithm has been used. This assumption is valid, as any decoding failures in the feedback path will directly lead to visible decoding failures, and consequently, this will not be an operation point for real reception. On the other hand, in order to limit the simulation time, the results were compared at a bit-error-rate (BER) of 10^{-4}.

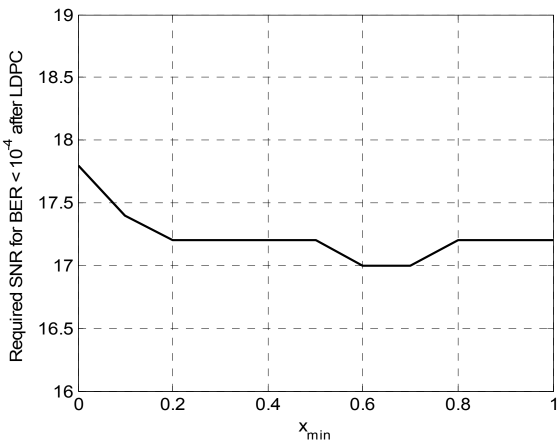

Figure 4: Required SNR for BER < 10^{-4} in the AWGN channel for different values of x_{min}, $x_{min}=0$ corresponds to the original CD3 algorithm, DVB-T2 parameters 16K FFT, Guard Interval 1/4, 256-QAM (normal), LDPC coderate 3/5 (long code), pilot pattern PP8

A. AWGN Channel Results

For the AWGN channel the influence of the factor x_{min} has been simulated first. Figure 4 depicts the required signal-to-noise ratio for the DVB-T2 parameter set 16K FFT, guard interval 1/4, 256-QAM (normal mapping) and the LDPC coderate 3/5 (long code). The figure shows clearly the gain of the proposed algorithm compared to the original CD3 algorithm ($x_{min}=0$). The avoidance of the inner constellation points reduces the required SNR by more than one dB, while the optimum point for this parameter set is approx. at $x_{min}=0.7$. If the value x_{min} is chosen too large, the required SNR again increases, as only few constellation points are used for the estimation of the channel.

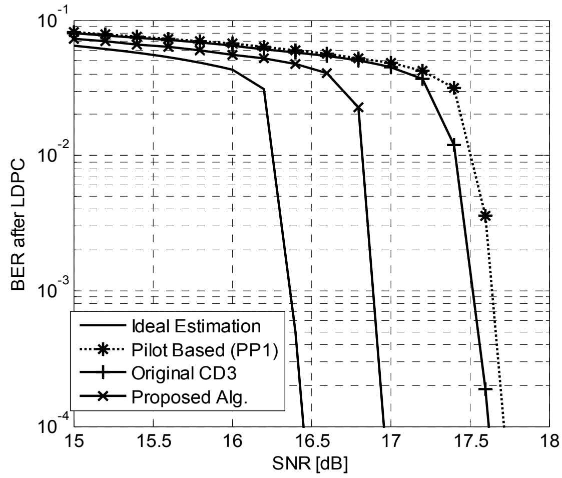

Figure 5: Comparison of BER vs. SNR for different channel estimation methods in the AWGN channel, $x_{min}=0.7$ for the proposed algorithm, DVB-T2 parameters 16K FFT, Guard Interval 1/4, 256-QAM (normal), LDPC coderate 3/5 (long code)

A direct comparison of the analyzed channel estimation techniques is shown in Figure 5. Naturally, the ideal channel estimation shows the highest performance, as it knows the channel perfectly. The pilot based channel estimation using the DVB-T2 pilot pattern PP1, which is also the pilot pattern used in DVB-T, shows a degradation of more than 1 dB, while the original CD3 algorithm only has a slightly better performance. In contrast, the proposed algorithm suffers a degradation of only 0.5 dB compared to the ideal estimation, and hence outperforms the two other algorithms.

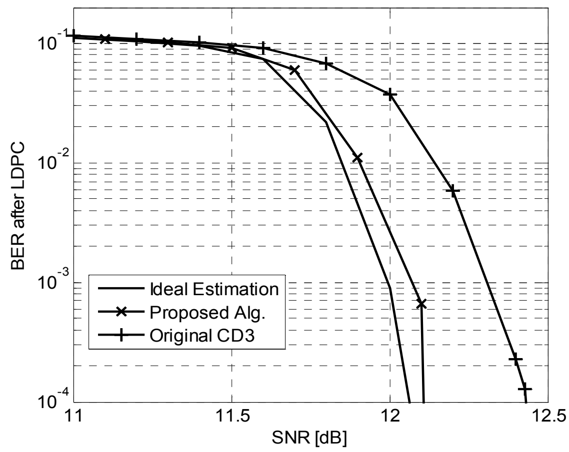

Figure 6: Comparison of BER vs. SNR for different channel estimation methods in the AWGN channel, $x_{min}=1.0$ for the proposed algorithm, DVB-T2 parameters 8K FFT, Guard Interval 1/4, 64-QAM (normal), LDPC coderate 3/5 (short code)

Similar results can also be obtained for 64-QAM constellations, as Figure 6 shows. However, as the ratio of the amplitudes between the inner and outer constellation points is smaller, the gain of the proposed algorithm is reduced to 0.4 dB.

B. Rayleigh Channel Results

The Rayleigh channel is a more realistic channel, but has higher demands than the AWGN case. Even in these channels, the proposed algorithm shows significant benefits compared to the original CD3 algorithm or pilot based channel estimation. A gain of more than 0.5 dB can be observed for the proposed algorithm in Figure 7.

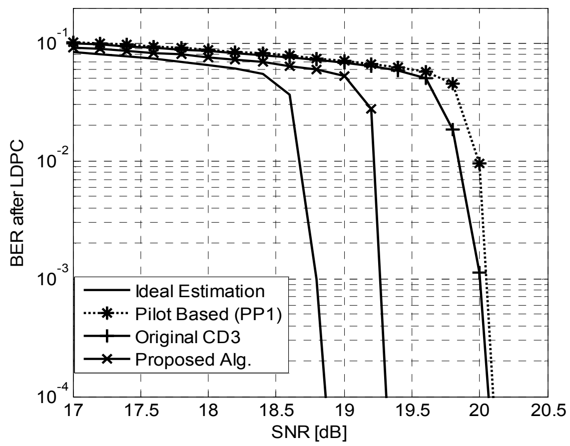

Figure 7: Comparison of BER vs. SNR for different channel estimation methods in the Rayleigh channel, $x_{min} = 0.7$ for the proposed algorithm, DVB-T2 parameters 16K FFT, Guard Interval 1/4, 256-QAM (normal), LDPC coderate 3/5 (long code)

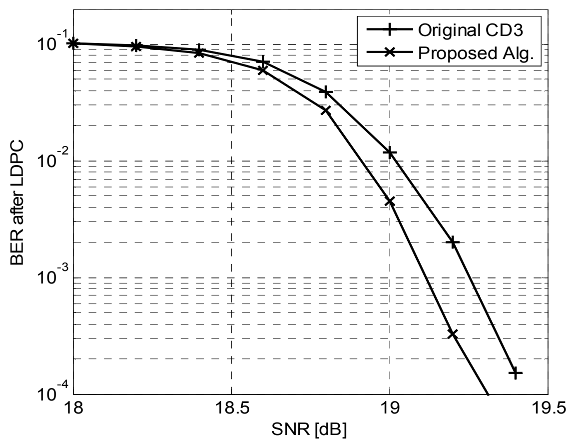

Figure 8: Comparison of BER vs. SNR for different channel estimation methods in the Rayleigh channel, $x_{min}=1$ for the proposed algorithm, DVB-T2 parameters 32K FFT, Guard Interval 1/8, 256-QAM (normal), LDPC coderate 3/5 (short code)

The gain in case of a shorter guard interval fraction is shown in Figure 8. As the bandwidth of the frequency filter is halved from guard interval 1/4 to 1/8, the resulting errors caused by the channel estimator are reduced significantly. Hence, the noise caused by the inner constellation points is reduced as well. Consequently, the additional gain of the proposed algorithm compared to the original CD3 technique reduces to 0.2 dB for the given parameter configuration.

C. Time Variant TU-6 Channel

A time variant channel has increased demands with respect to channel estimation. This especially holds for the CD3 and the proposed algorithm, as the channel equalization uses the channel transfer function of the previous OFDM symbol. While the degradation is negligible for lower Doppler frequencies (i.e. low receiver velocities), this degradation gets very important for high-mobility scenarios. Figure 9 shows simulation results for different channel estimation methods at 10 Hz Doppler, which corresponds to approx. 18 km/h receiver velocity at 600 MHz signal frequency.

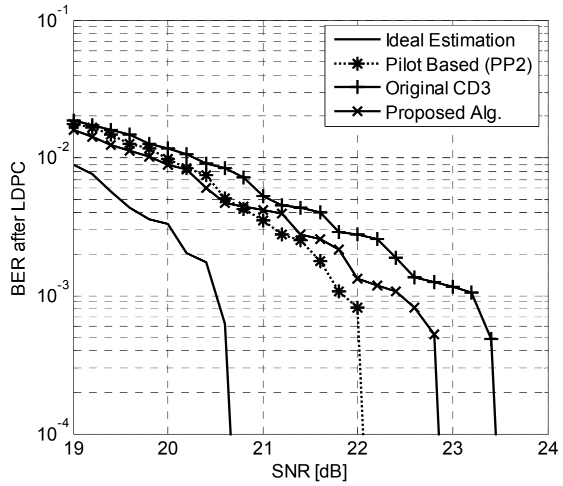

Figure 9: Comparison of BER vs. SNR for different channel estimation methods in the time variant TU-6 channel with 10 Hz Doppler, $x_{min}=0.7$ for the proposed algorithm, DVB-T2 parameters 8K FFT, Guard Interval 1/8, 64-QAM (normal), LDPC coderate 3/5 (long code)

As expected, the ideal channel estimation offers the highest performance. The degradation of the pilot based estimation is approx. 1 dB, while the pilot pattern PP2 has been used that is especially optimized for higher receiver velocities. The CD3 and the proposed algorithm show an additional degradation, while the proposed algorithm outperforms the original CD3 algorithm. However, the degradation compared to the pilot based channel estimation still remains in an acceptable range. It has to be mentioned that the jagged structure of the curves is caused by the limited simulation time. Nevertheless this is uncritical, as all simulations used exactly the same channel realization and the interesting aspects are the relative curves, and not their absolute values.

V. CONCLUSIONS

This document presents a new algorithm for channel estimation without pilots for DVB-T2 and other OFDM based transmission systems. It shows only a small performance loss compared to the ideal channel knowledge and outperforms the original CD3 algorithm, for which the PP8 pilot scheme of DVB-T2 was originally designed. Furthermore, the proposed algorithm outperforms the pilot-based channel estimation in stationary channels, while the loss in the time variant channel remains acceptable. However, the pilot pattern PP8 in addition to the proposed algorithm offers an increased spectral efficiency of approx. 8%, as the number of pilots is reduced significantly in comparison to pilot patterns PP1 and PP2. This increased spectral efficiency could also be converted to a lower coderate of the LDPC code, which will furthermore increase the robustness at similar payload bitrates.

An open topic remains the application of this algorithm for MISO transmission, as MISO requires the estimation of two separate channel transfer functions. Therefore, future work will especially focus on this area and also in the adaptation of scenarios with mobility.

ACKNOWLEDGMENT

The authors thank their colleagues at Mondragon University and at Technische Universitaet Braunschweig for their helpful comments. They are additionally grateful to the complete DVB-T2 group for the development of this great specification and also want to thank FURIA consortium for their help and funding.

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