Comparison of Finite-State Models for Simulating the DVB-H Link Layer Performance

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Abstract— **Digital video broadcasting for handheld terminals (DVB-H) is a broadcast system designed for high-speed data transmission in highly dispersive mobile channel conditions. In this paper, various finite-state models for simulating the transport stream packet error behavior of a DVB-H system operating in a multipath channel environment are presented and evaluated. The results from finite-state models are compared to measurement results. The model evaluation will focus on the accuracy of the models in replicating the high-order statistical properties of measured link layer transport stream error traces. Furthermore, the significance of these high-order error statistics such as variance in error burst length in simulating the link layer frame error rate of DVB-H will be considered.**

Keywords: DVB-H, packet transmission, channel modeling, Markov model, error statistics

I. INTRODUCTION

One of the strongest trends in modern telecommunication is the development of wireless wideband communication systems. Digital video broadcasting for handheld terminals (DVB-H) [1] is an excellent example of such a system. By nature, it encompasses various contemporary telecommunication challenges, such as achieving fast data rates in wireless networks, implementing power-limited mobile receivers, and the design of bandwidth-efficient single frequency networks (SFN). A common factor in all these tasks is the requirement of efficient operation in difficult channel conditions.

DVB-H is based on the terrestrial digital video broadcasting (DVB-T) standard [2]. It is designed to improve performance in mobile environments, to add flexibility in network planning and to enable efficient power control in handheld receivers. The data payload of DVB-H is in Internet Protocol (IP) packet form, which makes the system suitable for a variety of services in addition to streaming video. The IP packets are transmitted through a wideband downlink with a minimum bit rate of 2.49 Mbps, which is half the minimum bit rate of DVB-T. Currently it seems likely that DVB-H receivers will be incorporated into mobile phones, which will enable service providers to use the existing cellular network as an uplink. The actual downlink bit rate in the DVB-H transmission network, along with the receiver error performance, is dependent on several coding and modulation parameters. Since there are thousands of different combinations for the values of these parameters, the task of choosing the most suitable combination is not a trivial one.

To select the correct operating parameters for a communication system, one must be able to evaluate the performance of the system with different parameters in different channel conditions. Testing for example the DVB-H system with actual transmitters and receivers is time and cost-prohibitive at best. Dedicated system testing apparatus are also expensive and submit poorly to user modification and research outside the bounds set by the nominal system parameters. For these reasons, it is valuable to develop efficient software-based simulators. The performance of a software simulator can be enhanced by developing models to estimate system performance with suitable accuracy at required protocol levels. For example, to evaluate system performance at the physical level, a bit-accurate waveform channel model is required to estimate the effects of the transfer channel. On the other hand, at the IP or TS (Transport Stream) levels, it is not necessary to know the bit-level error behavior of the system; rather, a block error model is quite sufficient for most simulation purposes.

The utilization of Markov models to describe the behavior of block or packet transmission in fading channels is investigated in [3]–[5]. In [3], a two-state Markov model was used to model a flat Rayleigh fading channel. In [4] authors proposed the Markov based trace analysis algorithm for modelling network channels that experience time varying error statistics. In [5] the four-state run length Markov model was applied in simulating mobile and ad hoc networks. To the extent of the authors' knowledge, no studies on the application of finite-state models in DVB-H simulations have been previously published. As DVB-H in general is still under development, few papers regarding the system have been published altogether.

In this paper, the methods mentioned in the previous paragraph are applied in modeling the error statistics of DVB-H link layer TS packets. The models are then analyzed by comparing them to measurement results. Criteria for assessing the packet channel models are TS packet error rate (PER), average burst error length (ABEL), and variance in burst error length (VBEL). These criteria are affected by the signal-to-noise ratio (SNR) and time-variance of the physical channel, but also by the interleaving and error correction performed in the communication system. Selection of the abovementioned statistics as measures of the models' accuracy follows the approach used in [3] to study the performance of the two-state Markov model. Simulations indicate that accurate reproduction of these error statistics results in accurate simulation results at the protocal layer under inspection. More specifically, the benefits of obtaining knowledge on high-order error statistics will be studied by applying TS packet error traces generated with the abovementioned models in link layer frame error rate (FER) simulations. The results thus obtained are then compared to simulations using measured TS packet error traces. In addition to error statistics comparison, capability of model parametrization, i.e. how easily physical system parameters are mapped to model parameters, is discussed. The main difficulty in parameterizing any finite-state block error model for DVB-H is the great number of combinations of system parameters that affect the error statistics to be evaluated.

II. THE LINK LAYER IN DVB-H

Fig. 1 shows the link layer IP encapsulation in DVB-H described in [1]. The network layer IP datagrams are first read column-wise into the application data table part of the MPE-FEC (Forward Error Correction for MultiProtocol Encapsulated data) frame, which consists of a total of 191 columns. The application data table is encoded row-wise using a systematic Reed-Solomon code; the resulting 64 correction bytes per row are then added to the RS data table part of the MPE-FEC frame. The row-wise encoding of the application data arranged into columns results in a virtual interleaving effect that is in fact the basis of the improved Doppler performance of DVB-H as compared to DVB-T. Furthermore, in simulating the performance of DVB-H link layer forward error correction, the link layer frame error rate is greatly affected by the error burst statistics of lower protocol levels, as will be shown in section IV. The MPE-FEC code rate (cr) can be adjusted by zero-padding either the application data table, or the RS data table. The added zeros are not transmitted, however. After the MPE-FEC frame is constructed, the application data table IP datagrams are encapsulated into MPE sections. In a similar fashion, the RS data table columns are encapsulated into MPE-FEC sections. The encapsulated MPE and MPE-FEC sections are partitioned into TS packets in MPEG-2 format [7] and transmitted through the modified DVB-T modulator in the physical layer. If forward error correction is not used, the whole MPE-FEC frame is filled with IP data. This also removes the virtual interleaving mentioned above. The effect of virtual interleaving will be studied in more detail in section IV, where the MPE-FEC frame error rate with and without forward error correction (using code rates 3/4 and 1, respectively) is evaluated using transport stream packet error traces with different error burst length statistics.

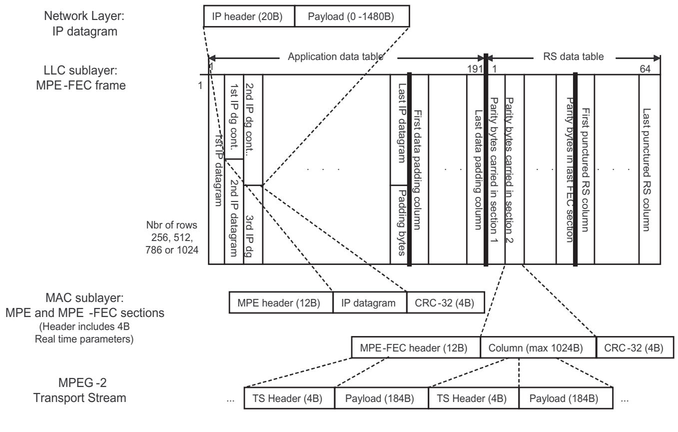

Fig. 1. IP encapsulation in the DVB-H link layer [6]

III. FINITE-STATE PACKET ERROR MODELS

In evaluating error statistics of high protocol layers of the DVB-H system, such as the MPE-FEC frame error rate, detailed information on the bit-level error distribution in the transport stream packets may be irrelevant. For simulation purposes, a model that determines whether a TS packet contains errors or not is sufficient as a tool for FER evaluation. In practice, when a TS packet contains eight erroneous bytes or less, the packet can be labeled error-free. This is due to the eight-byte correction capability of the RS(204,188, t = 8) code used in the DVB-T modulator. In the following, ways of modelling measured TS packet error behaviour according to the block error criterion presented above are considered. Different models are compared using the resulting PER, ABEL and VBEL values when the signal-to-noise ratio of 17 dB is used. Summary of model output statistics comparison is presented in table I.

A. Measurement Setup

Fig. 2 shows the measurement setup for obtaining the error traces used in constructing the finite-state models. MPEG-2 source data was input into a DVB-T modulator operating with various combinations of system parameters. The modulated signal was passed through a hardware channel simulator that used a COST 207 TU6 (six-tap typical urban) multipath channel model [8]. Noise was then added to the signal to obtain various SNR values. The noisy signal was input into a DVB-T/H receiver and subsequent logic analyzer to produce TS packet error traces. These traces consist of a series of zeros and ones, where zeros indicate TS packets containing too many errors for the physical layer outer decoder to correct, and ones indicate error-free TS packets. Measured error statistics for 17 dB SNR are as follows: PER=0.029, ABEL=14.187, and VBEL=1088.

B. Memoryless Channel Model

If transport stream packets experienced independent and identically distributed (i.i.d.) behavior, the channel would be memoryless, and it could be modeled as a binary symmetric channel by drawing one uniformly distributed random number per transmitted packet to decide if the packet is in error or not [9]. However, the time interleaving capability of the DVB-H demodulator is limited, and the memoryless channel model fails to produce the error behavior of transport stream packet errors generated in time-variant mobile channels. In

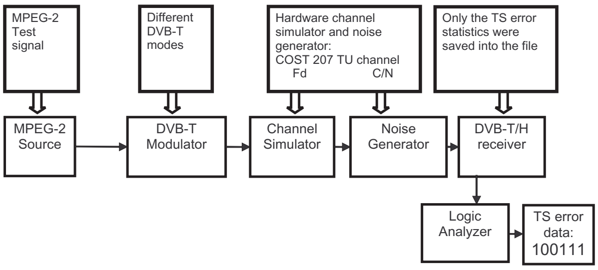

Fig. 2. Measurement setup for obtaining TS packet error traces

Fig. 3, the measured probability distribution function (PDF) of TS packet error burst lengths is compared to an error trace generated using a memoryless channel model. The latter reproduces the packet error rate of the measurements, PER value being 0.029, but fails to reproduce the average burst error length and variance in burst error length, which are 1.028 and 0.029 respectively.

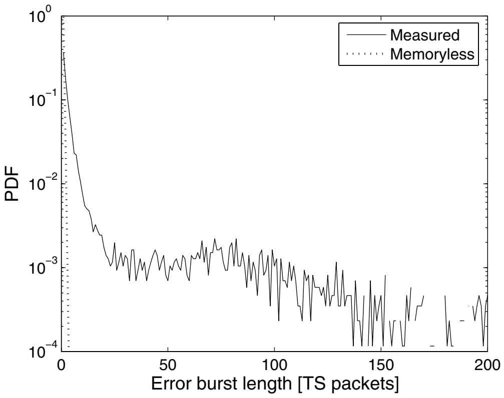

Fig. 3. Error statistics of the memoryless channel model compared to a measured error trace (SNR 17 dB)

C. Two-state Markov Model

To better model the error bursts in the measurements, a two-state Markov model [3] is constructed. This model is designed to reproduce the average error rate and average burst error lengths of the measured error traces, and is in fact an example of the Gilbert model [9] with probability of error equal to one. The advantages of this model are that the model parameters are very easy to calculate, and the output sequence matches the aforementioned statistics very well with PER=0.029 and ABEL=14.251 (Figures 7 and 8). However, the two-state Markov model doesn't replicate the distribution of error burst lengths of the measured error sequence. As stated in [10], the error cluster distribution of a single error state model can be described with a single exponential. When expressed in logarithmic form, this makes for a linear function. As can be seen in Fig. 4, this kind of linear approximation is insufficient in describing accurately the error behaviour of the measured channel. More specifically, the two-state Markov model does not replicate the variance in burst error length of the measured error traces (VBEL=185). This is due to the fact that the statistics that determine the model parameters are averaged over a long period, thus losing information on the time-dependent error statistics of the channel.

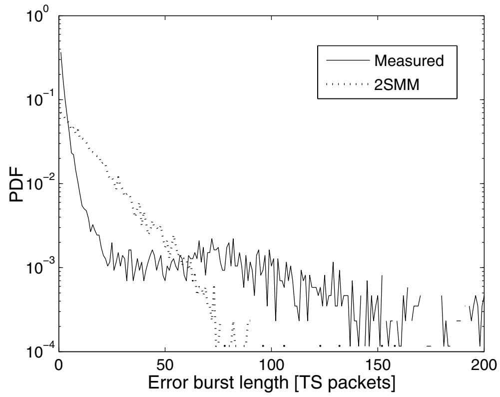

Fig. 4. Error statistics of the two-state Markov model compared to a measured error trace (SNR 17 dB)

D. Markov-based Trace Analysis Algorithm

The Markov-based trace analysis (MTA) algorithm [4] is in effect a hierarchical two-state Markov model that takes into account the need for time-variant finite-state model parameters. Finding the parameter values for this model is considerably more complicated than with the two-state Markov model, and the PER and ABEL are not reproduced as accurately as with the simpler model, values being 0.031 and 16.079 respectively. However, the measured variance in burst error length is better reproduced (VBEL=483) than with the two-state model (Table I). This can also be seen in Figures 5 and 9. Also, as the MTA is by definition an algorithm for analyzing existing measurements, or error traces, it is difficult to parameterize the model as a function of DVB-H system parameters. Simpler models, such as the two-state Markov model, or even the four-state run length model to be described shortly, offer more possibilities for parameterization.

E. Four-state Run Length Model

The principle of the four-state run length model [5] is to directly estimate the good and bad state length distribution functions of measured error traces. Thus the main problem with this model is that of accurate function approximation, which can in many cases be challenging to implement in a rigid algorithmic manner. However, when the model parameters are selected correctly, this produces a good estimation of the measured error statistics, as can be seen in Fig. 6. Values for error statistics are PER=0.030, ABEL=11.605, and VBEL=816. Also, the model is described with a relatively small set of parameters, which could conceivably be determined as functions of relevant DVB-H system variables, enabling the parameterization considered previously.

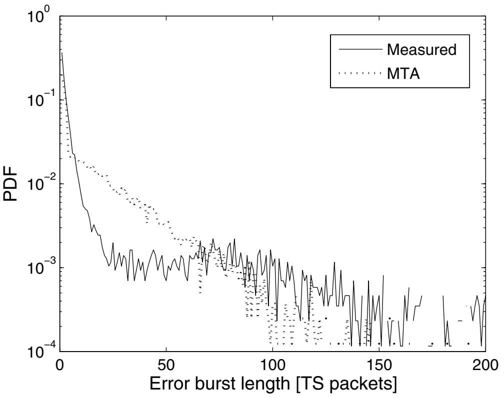

Fig. 5. Error statistics of the MTA model compared to a measured error trace (SNR 17 dB)

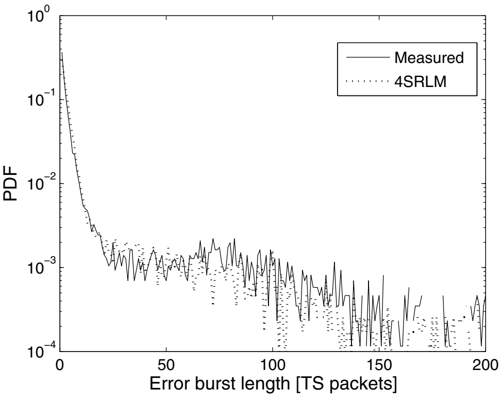

Fig. 6. Error statistics of the four-state run length model compared to a measured error trace (SNR 17 dB)

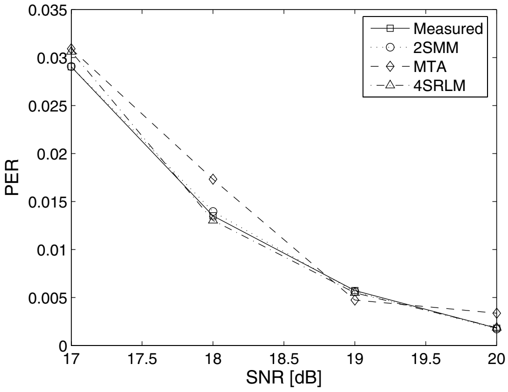

Fig. 7. Packet error rates obtained with the implemented finite-state models

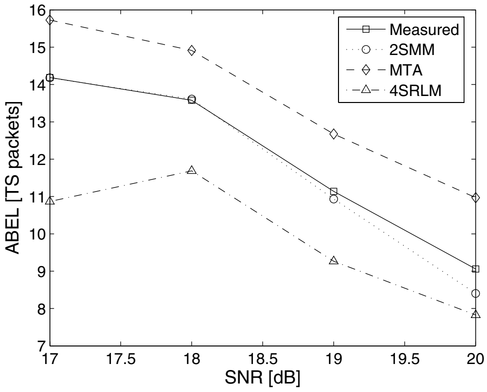

Fig. 8. Average burst error lengths obtained with the implemented finite-state models

IV. EFFECT OF ERROR BURST STATISTICS ON THE LINK LAYER FRAME ERROR RATE

To evaluate the importance of constructing error traces with correct statistical properties, the MPE-FEC frame error rate with and without the FEC was evaluated. This was done using a DVB-H MPE-FEC simulator that uses TS erasure decoding, that is, Reed-Solomon erasure decoding, where the erasure information is obtained from the TS packet transport error indicator defined in [7]. The simulations were run using measured TS packet error traces and traces generated with the finite-state models with memory presented in section III. The PER, ABEL, and VBEL of the aforementioned traces in a SNR range of 17 to 20 dB are presented in Figures 7, 8, and 9. As an example, the values for these statistics at the 17 dB point are given in table I. Figures 10 and 11 show the resulting link layer frame error rate with and without forward error correction, respectively. It should be noted that although the two-state model outperforms the other two finite-state models in terms of PER and ABEL accuracy, the resulting FER is the least accurate. This emphasizes the importance of also accounting for the variance in burst error length. In this case, the output of the two-state model can be characterized as a consistent sequence of short error bursts at relatively frequent intervals. When forward error correction is used, these short error bursts are effectively dispersed by the virtual interleaving presented in section II, resulting in a considerably lower frame error rate than with the other error traces (Fig. 10).

TABLE I
COMPARISON OF MODEL OUTPUT STATISTICS (SNR 17 dB)

	PER	ABEL	VBEL
Measurements	0.029	14.187	1088
Memoryless model	0.029	1.028	0.0290
2-state model	0.029	14.251	185
MTA	0.031	16.079	483
4-state model	0.030	11.605	816

Without forward error correction, the effect of insufficiently large error burst length variance is opposite compared to the previous case. Again, with the two-state model the errors appear relatively frequently in short bursts, increasing the probability that any given MPE-FEC frame will contain errors. With a larger error burst length variance, there is a tendency towards longer and more widely spaced error bursts, enabling more frames to be transmitted during the error-free intervals. The resulting difference in frame error rates, shown in Fig. 11, further emphasizes the effect of VBEL in finite-state modeling

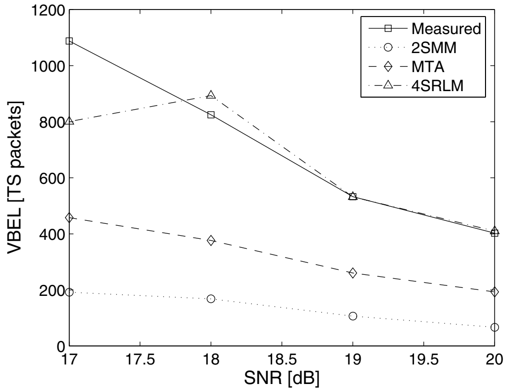

Fig. 9. Variances in burst error length obtained with the implemented finite-state models

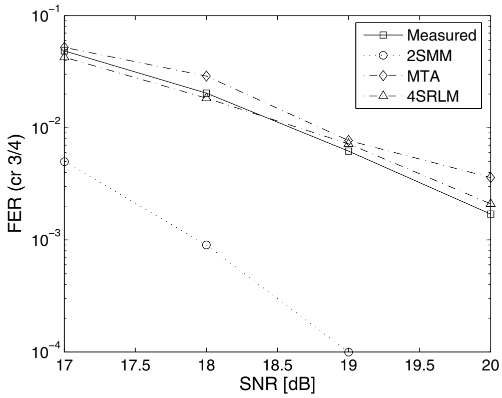

Fig. 10. Resulting forward error coded frame error rates

the TS error performance.

Figures 9, 10, and 11 raise a question as to why use of the MTA model produces such accurate FER values. The average burst error lengths of the MTA traces are not significantly more accurate than with the four-state run length model, and the accuracy of the variances in burst error lengths obtained with the MTA model falls far below that of the four-state model. Still the MTA model outperforms the four-state model in terms of FER accuracy in the uncoded case. Also, the coded frame error rate with the MTA model is only slightly less accurate than with the four-state model. Explanation for this behaviour is that the longer average burst error length of the MTA output compensates for the lower error burst length variance in generating link layer frame errors, as it seems that the FER is quite sensitive to both of these statistical properties of the input TS packet error stream.

V. CONCLUSION

Four finite-state models for estimating DVB-H transport stream packet error traces were applied and evaluated. Evaluation of these models showed that the choice of modeling approach has great impact on the statistical accuracy of a Markov model. Furthermore, the importance of reproducing also the high-order statistical properties of measured error traces was shown by simulating the link layer frame error rates resulting from the use of various finite-state models. It could be clearly seen that failing to reproduce the variance in error burst length causes inaccurate results in higher protocol level simulations. This sets demands on the complexity of the finite-state models used in simulations. While a simple approach such as the two-state Markov model provides good possibilities for model parameterization as a function of physical system parameters, it may lack the capacity to produce statistically accurate results. On the other hand, sufficient model simplicity to enable parameterization is essential in utilizing Markov models, as this enables simulating conditions that have not been measured. This detachment from measurements, along with the obvious computational efficiency of finite-state channel models, is an essential motivation for utilizing Markov models instead of pure statistical analysis and reproduction of measured error distributions.

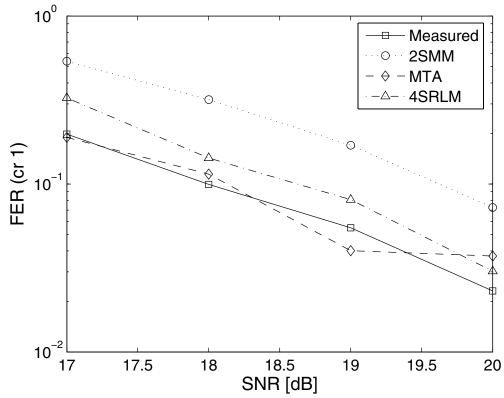

Fig. 11. Resulting uncoded frame error rates

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