Error Models for the Transport Stream Packet Channel in the DVB-H Link Layer

[1]Jussi Poikonen and [2]Jarkko Paavola
[1]The Graduate School in Electronics, Telecommunications and Automation (GETA)
[2]Turku Centre for Computer Science (TUCS)
[1,2]Department of Information Technology, University of Turku
Lemminkäisenkatu 14 A, FI-20520 Turku, FINLAND
[1]jussi.poikonen@utu.fi,[2]jarkko.paavola@utu.fi

***Abstract*— Digital video broadcasting for hand held terminals (DVB-H) is a broadcast system designed for high-speed data transmission in highly dispersive mobile channel conditions. In this paper, methods of reproducing the statistical properties of measured DVB-H packet error traces are presented. Statistical and finite-state modeling approaches are found to be suitable for simulating the error performance of a DVB-H system operating in typical urban channel conditions. Evaluation of these models focuses on the accuracy of the models in replicating the high-order statistical properties of measured DVB-H transport stream error traces. Also, the effect of these error statistics on the DVB-H link layer frame error rate is considered.**
Keywords: DVB-H, packet transmission, channel modeling, error statistics

I. Introduction

One of the strongest trends in modern telecommunication is the development of wireless wideband communication systems. Digital video broadcasting for hand held 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.

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, 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 sufficient for many simulation purposes.

In this paper, two different approaches for constructing DVB-H TS packet error traces are presented and compared in terms of accuracy of performance estimation and required simulator complexity. The modeling methods are based on finite-state machine and statistical approaches. For both methods, the required model parameters are derived from actual measurement results. First, the link layer of DVB-H along with the measurement setup used for obtaining the error traces used in constructing the models is presented briefly in section II. In section III, finite-state and statistical block error models are described and applied in the DVB-H link layer. An evaluation of the abovementioned models is presented in section IV.

II. DVB-H Link Layer

A. Protocol

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 [2]; 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.

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 [5] and transmitted through the 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.

B. Measurement Setup

Fig. 2 shows the measurement setup used for obtaining transport stream error traces. MPEG-2 source data was input

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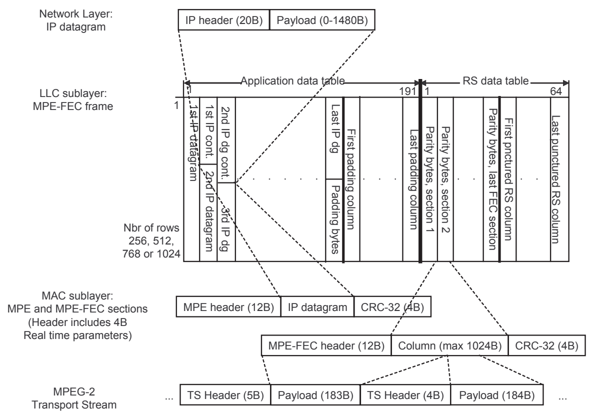

Fig. 1. IP encapsulation in the DVB-H link layer [4]

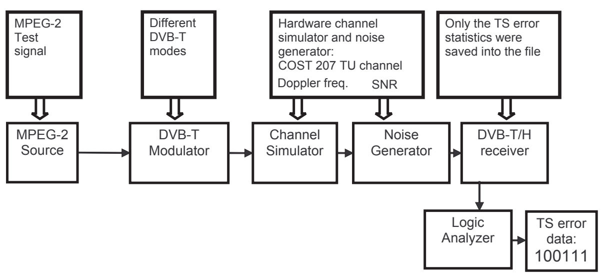

Fig. 2. Measurement setup for obtaining TS packet error traces

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 [6]. Noise was then added to the signal to obtain various signal-to-noise ratio (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.

It should be noted that the measured error traces should be lengthy enough to represent the stationary error statistics of the channel conditions under inspection. The stationarity of DVB-H error traces was evaluated using the Runs Test summarized in [8]. In this case, a run refers to a series of consecutive packet errors, or zeros in the measured error traces. The principle of the Runs Test is to divide the measured trace into segments of equal lengths, compute the lengths of runs in each segment, count the number of runs of length above and below the median value for run lengths in the trace, and finally compute a histogram for the number of runs counted. Now, for a stationary trace, the number of runs distribution between the 0.05 and 0.95 cutoffs will be close to 90%. As can be seen in the example of Fig. 3, the measured error trace starts

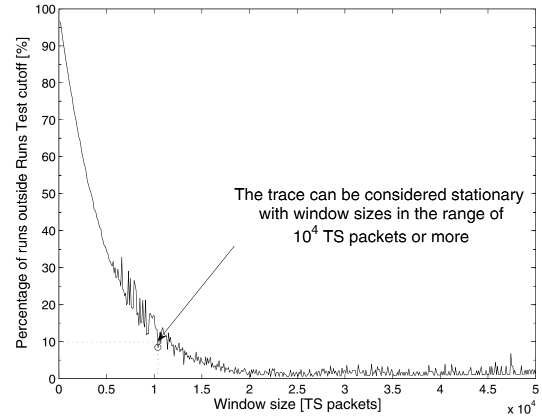

Fig. 3. Stationarity of a DVB-H error trace as a function of the observation window size

to exhibit stationary properties with window sizes greater than approximately 10^4 TS packets (SNR=17 dB, 10 Hz Doppler frequency, f_d). The measured error traces used in constructing the models evaluated in this paper were of lengths greater than 10^6 TS packets.

III. Packet error models

In evaluating error statistics of high protocol layers of the DVB-H system, such as the MPE-FEC frame error rate (FER), 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.

The utilization of Markov models [7] to describe the behavior of block or packet transmission in fading channels is investigated in [8]–[10]. In [9], a two-state Markov model was used to model a flat Rayleigh fading channel. In [8] authors proposed the Markov based trace analysis (MTA) algorithm for modeling network channels that experience time varying error statistics. In [10] the four-state run length Markov model was applied in simulating mobile and ad hoc networks. There are several advantages in utilizing finite-state models for generating packet error traces to estimate measured error statistics. The required memory and data storage capacity is reduced considerably compared to using measured error traces in simulations. Also, as finite-state models are generative by nature, they produce random, but statistically consistent output data. Moreover, the lengths of the output traces are not limited by the lengths of the original measurements used in evaluating model parameters.

In [11], finite state models from [8]–[10] were applied in DVB-H link layer simulations. The significance of reproducing the high-order statistical properties of measured error traces was shown by comparing the link layer frame error rates resulting from the use of the abovementioned finite-state models to rates obtained using corresponding measured error traces. Also, the possibility of model parameterization, that is, determining the finite-state model parameters as functions of specific system and channel variables was considered. Results from [11] are summarized in table I and in figures 8-12, which include also results from the statistical model to be presented in section III-B. The four-state run length model will be presented in more detail in section III-A, since in overall comparison it seems to be the most applicable in practice for DVB-H link layer simulations, although the Markov based trace analysis outperforms it in some statistics.

Statistical modeling, which is another approach for packet error trace modeling, is presented in section III-B. It will be shown that by calculating error distributions from measurement results an accurate simulation model can be created, which is also theoretically simpler than finite-state modeling. A major disadvantage of this modeling approach is that it is designed to replicate the error statistics of individual measurements, making it unsuitable for parameterization.

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 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 [9] 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 protocol layer under inspection.

In the following, the methods used in creating a four-state Markov model or a statistical error model from measurement results are presented. The resulting error trace models are illustrated and compared to measurement results in figures 5 and 7 with physical layer parameters of SNR= 17 dB and $f_d = 10$ Hz.

A. Four-state Run Length Model

The basic principle of the four state run length model [10] is to evaluate measured good and bad state length distributions using functions of the form

$$f(n) = p(1-\alpha)\alpha^n + (1-p)(1-\beta)\beta^n \tag{1}$$

where α, β, and p are parameters suitably chosen to approximate the desired run length distribution, and n is the run duration. In terms of finite-state modeling, these functions can be realized by splitting both the good state and the bad state of a two state model into long and short states, producing a simple four state Markov model, as shown in Fig. 4.

The parameters α, β, and p can be evaluated for example by dividing (1) into two functions:

$$f_1(n) = p(1-\alpha)\alpha^n \tag{2}$$

$$f_2(n) = (1-p)(1-\beta)\beta^n \tag{3}$$

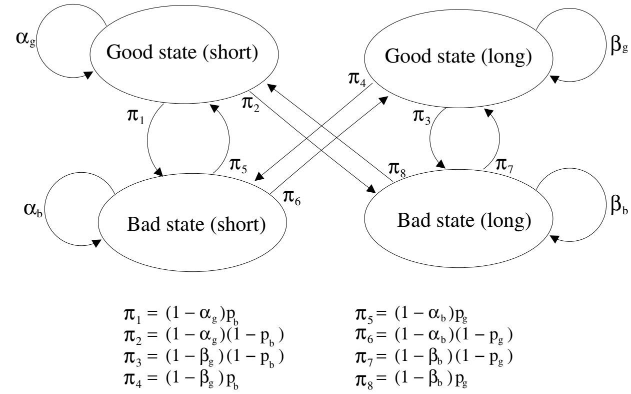

Fig. 4. State diagram of the four state run length model

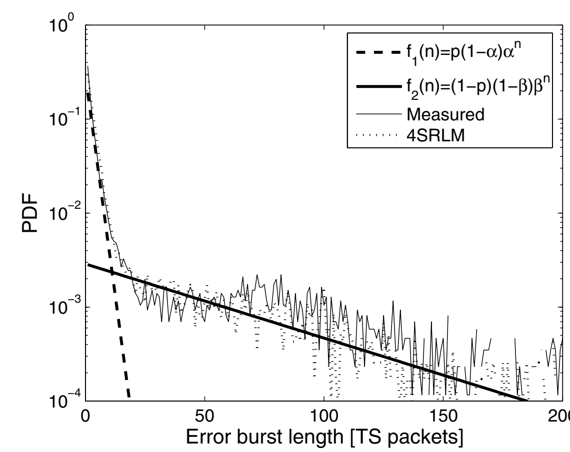

Fig. 5. Bad state length probability distribution function (PDF) of the four-state run length model compared to a measured error trace. Also shown are the functions used for approximating the measured PDF.

If we now take the logarithm of (2) and (3), we get:

$$\log f_1(n) = \log p + \log(1-\alpha) + n \log \alpha \tag{4}$$

$$\log f_2(n) = \log(1-p) + \log(1-\beta) + n \log \beta \tag{5}$$

Thus in the logarithmic scale, (1) can be approximated as a sum of two linear functions of n. A functional approach to determining the model parameters is now to select α and β by estimating $\log\alpha$ and $\log\beta$ as the slopes of the short and long run duration parts, respectively, of the distribution to be evaluated. The parameter p can then be selected to produce the best fit to the distribution under evaluation. The procedure is illustrated in Fig. 5. Slopes of $f_1(n)$ and $f_2(n)$ are estimated manually. The values for the model parameters are: $\alpha_g = 0.650$, $\beta_g = 0.999$, $p_g = 0.657$, $\alpha_b = 0.650$, $\beta_b = 0.982$, and $p_b = 0.840$. The resulting error statistics are presented in table I.

B. Statistical error model

In this section, a statistical method of generating packet error traces is presented. The model is in effect the top level of the Markov based trace analysis algorithm [8], but with the

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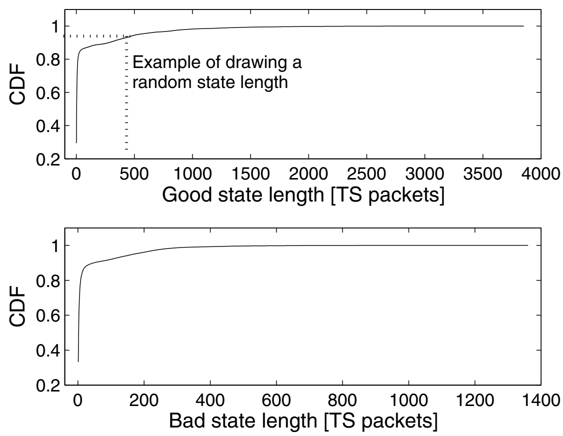

Fig. 6. Selecting random state lengths using the stored CDFs

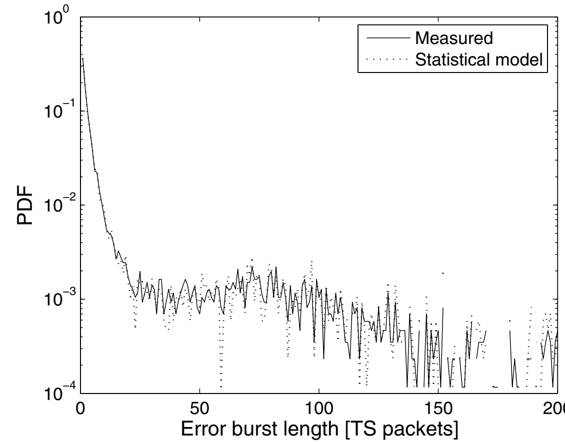

Fig. 7. Bad state length probability distribution function of the statistical model compared to a measured error trace (SNR 17 dB)

exponentially approximated state length cumulative distribution functions replaced by measured cumulative distribution functions (CDF). This approach is a compromise between the MTA algorithm and utilizing measured error traces directly; in any case it is meant for reproducing the statistical properties of specific measured error traces. The procedure is theoretically simple compared to the four-state run length model, but retains the advantages of finite-state modeling discussed earlier, namely statistically coherent output sequences of arbitrary length, and a reduced data storage requirement compared to using measured error traces. Moreover, it will be shown in section IV, that the accuracy of the output statistics of this model is consistently better than with any single one of the finite-state models considered in [11].

In the statistical error model, the cumulative distribution functions of the good and bad state lengths of measured error traces are first calculated and stored. Then, following the algorithm presented in [8] (steps 1 – 2.c are unchanged):

1. Choose the number of packets, *N*, to generate in the artificial trace.
2. The algorithm repeats the following steps until all *N* frames have been generated:
   (a) Determine g_{len}, the error-free state length from the error-free state length distribution.
   (b) Determine b_{len}, the lossy state length from the error-free state length distribution.
   (c) Generate g_{len} error-free packets
   (d) Generate b_{len} erroneous packets

The state lengths g_{len} and b_{len} are calculated with the inverse transformation method also used in [8], where sample values, x, of a random variable X with a CDF $F(X)$ are obtained by generating uniformly distributed random variables u and calculating $x = F^{-1}(u)$. The procedure is illustrated in Fig. 6.

The error traces thus obtained accurately match the state length distributions of the corresponding measurements. This is illustrated by the error burst length probability distribution functions shown in Fig. 7 and numerical values in table I. The most significant statistical inaccuracy in this modeling approach is that it does not take into account the possible correlation between successive state lengths. In DVB-H link layer simulations, however, this does not seem to have an adverse effect on the performance of the model, as will be shown in the following section.

IV. Evaluation of the Models

A. Hardware Requirements

Computationally the statistical model described in the previous section requires drawing one random number per n simulated packets, where n is random and follows the state length probability distribution functions of the measured error trace. Thus the statistical model is computationally even more efficient than typical finite-state models such as the two-state model [9] and the four-state run length model [10], which require drawing at least one random number per simulated packet.

The memory and data storage requirements with the statistical model are greater than with finite-state models, which are typically defined by relatively small parameter sets, while the statistical model requires two cumulative distribution functions per measured error trace to be stored. On the other hand, the stored CDFs require considerably less memory than the measurements used to obtain them. For example, the measured DVB-H error traces discussed in this paper require 4.58 gigabytes of disk space, while the CDFs used in reproducing the statistics of these traces require only 5.73 megabytes. Thus, while the statistical approach is not as memory-efficient as the finite-state models, there was still a 99.87 percent reduction in the storage capacity required, compared to using measured error traces.

B. Parameterization capability

Model parameterization capability refers to the possibility of constructing packet error models of a specific channel based on a set of system and channel variables, or parameters. In

TABLE I

COMPARISON OF MODEL STATISTICS (SNR= 17 dB, $f_d = 10\ Hz$)

	PER	ABEL	VBEL	FER: cr 3/4	FER: cr 1
Measurements	0.029	14.187	1088	0.049	0.198
2-state [11]	0.029	14.251	185	0.005	0.539
MTA [11]	0.031	16.079	483	0.052	0.190
4-state	0.030	11.605	816	0.043	0.326
Statistical	0.030	14.755	1170	0.054	0.198

DVB-H, for example, this would mean defining packet error models based on the channel SNR, Doppler frequency, and possibly the code rates and modulation modes used in the system. With simple finite-state models such as the two-state model [9], this is viable: the finite-state model is defined by the PER and ABEL observed in measurements, and these statistics can in turn be approximated as functions of the channel SNR, for example. For more complicated finite-state models such as the four-state run length model, this kind of approximation is more difficult, but still conceivable, as the model is defined by a relatively small set of parameters. The statistical model described in section III-B on the other hand is based on storing and reproducing measured error statistics. As the state length distributions obtained with the typical urban channel model don't submit well to simple function approximation, the parameterization of the statistical model is a difficult task.

C. Statistical Accuracy

The accuracy of the four-state and statistical models' output statistics is summarized in Table I, and Figures 8, 9, and 10, where statistical properties are illustrated as a function of SNR with $f_d = 10$ Hz. To provide ground for more thorough comparison, the statistics of the two-state and MTA models evaluated in [11] are also presented. The measured error statistics with a 17 dB signal-to-noise ratio are PER=0.029, ABEL=14.187, and VBEL=1088. Using the statistical model, the packet error rate (Fig. 8) is as accurately reproduced (PER=0.030 at SNR 17 dB) as with the four-state model. Again with the statistical model, the average burst error length (Fig. 9) is 14.755, which is more accurate than with the four-state model (ABEL=11.605). This applies also to the VBEL (Fig. 10), which is 1170 at 17 dB SNR, compared to the VBEL value 816 produced by the four-state run length model.

D. Effect of statistical accuracy on frame error rate

To compare the performance of the models, the DVB-H MPE-FEC frame error rate with and without the FEC was evaluated. This was done using an 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 [5]. The simulations were run using measured TS packet error traces, traces generated with the finite-state models described in [11], and the statistical model presented in section III-B. Figures 11 and 12 show the resulting link layer frame error rate with and without forward error correction, respectively.

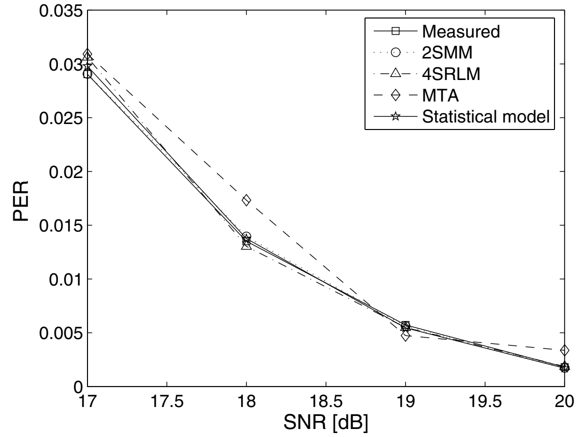

Fig. 8. Packet error rates obtained with the implemented models

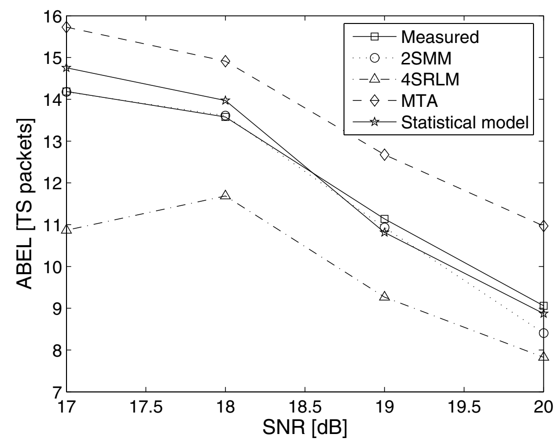

Fig. 9. Average burst error lengths obtained with the implemented models

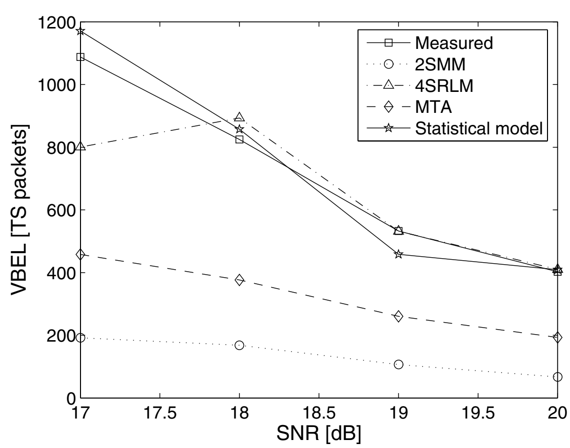

Fig. 10. Variances in burst error length obtained with the implemented models

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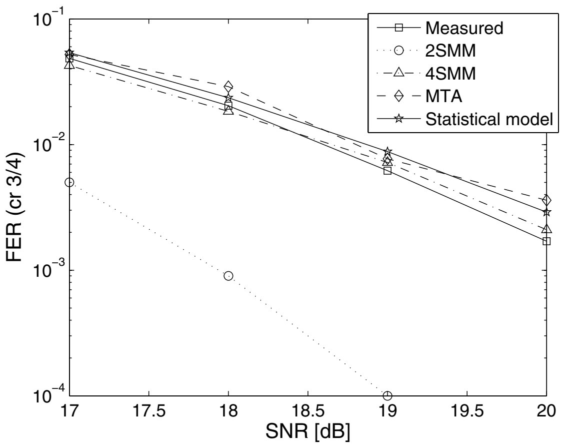

Fig. 11. Resulting forward error coded frame error rates

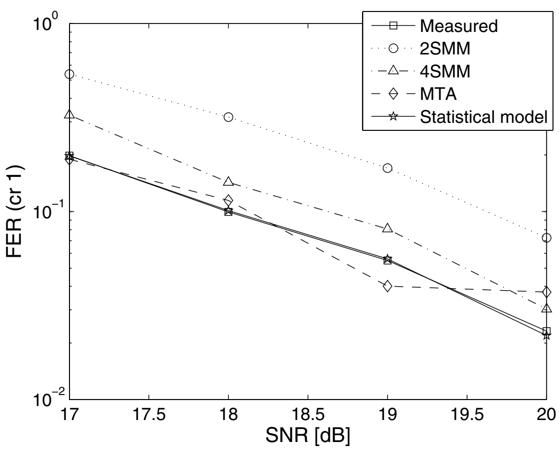

Fig. 12. Resulting uncoded frame error rates

The combined accuracy of the output statistics presented in Figures 8, 9, and 10 has a great effect on resulting DVB-H link layer frame rate estimation. For example, 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 of the DVB-H link layer, resulting in a considerably lower frame error rate than with the other error traces (Fig. 11). No conclusion can be drawn as to which of the other models performs best in simulating the coded frame error rate, as the statistical model, the four-state run length model, and the Markov-based trace analysis algorithm all produce good results. Without the FEC-induced virtual interleaving, the differences in the statistical accuracy of the model outputs are emphasized, resulting in the statistical model producing very accurate frame error rates (Fig. 12, Table I).

V. CONCLUSION

In this paper, two methods of reproducing the statistical properties of measured packet error traces of a DVB-H system operating in a typical urban channel were described and evaluated. The finite-state machine approach of the four-state run length model was shown to produce good results in DVB-H link layer simulations. Also, finite-state models hold the possibility of model parameterization, which is a good topic for further study. Furthermore, both the four-state model and the statistical model provide random output sequences with arbitrary lengths, which is one advantage of the generative finite-state models typically used in corresponding scenarios. The main disadvantage of the statistical model is that a considerable amount of data still has to be stored per measurement, which makes the model an ill-fitting candidate for parameterization. On the other hand, the total data storage requirement with the statistical model presented was in this case found to be only 0.13 percent of the space required for storing measured error traces. Moreover, the statistical accuracy and subsequent performance in system simulations of the presented model surpasses that of the finite-state models previously found to be most suitable for estimating the channel under inspection. Especially in simulating the DVB-H link layer rates without forward error correction, the statistical model produced excellent results. Also, as data storage in the scale needed for this model is trivial with modern computers, the statistical model is a considerable option if sufficient measurement data is available.

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